Modelos Quantitativos de Bacias Sedimentares

AGG0314

Aula 3 - Estrutura interna da Terra e Geodinâmica das placas litosféricas

Physics of the Earth and Planetary Interiors, 25 (1981) 297–356
Elsevier Scientific Publishing Company, Amsterdam – Printed in The Netherlands

Preliminary reference Earth model *

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[2] *Seismological Laboratory, California Institute of Technology, Pasadena, CA 91125 (U.S.A.)*

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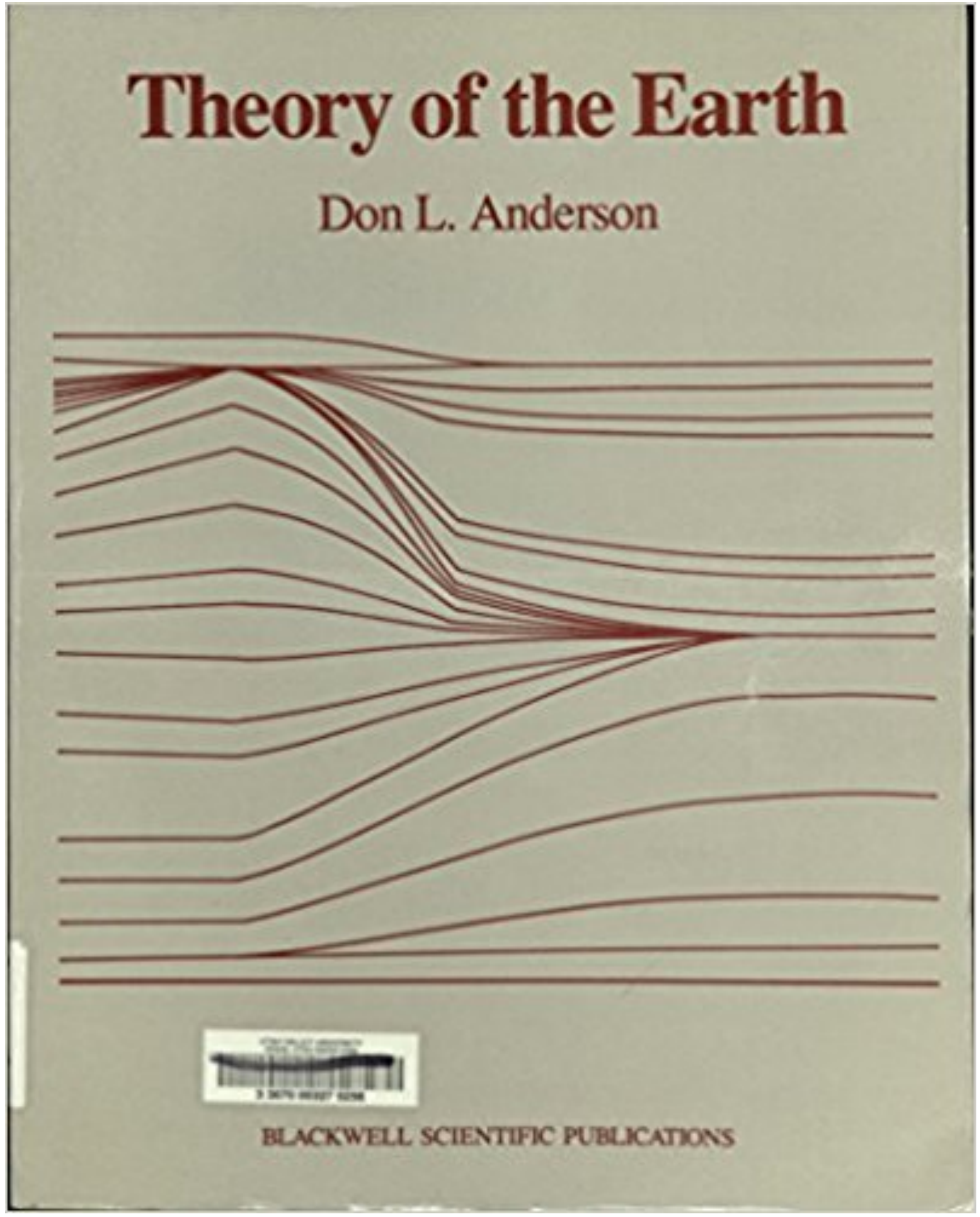
Dziewonski, A.M. and Anderson, D.L., 1981. Preliminary reference Earth model. Phys. Earth Planet. Inter., 25: 297–356.

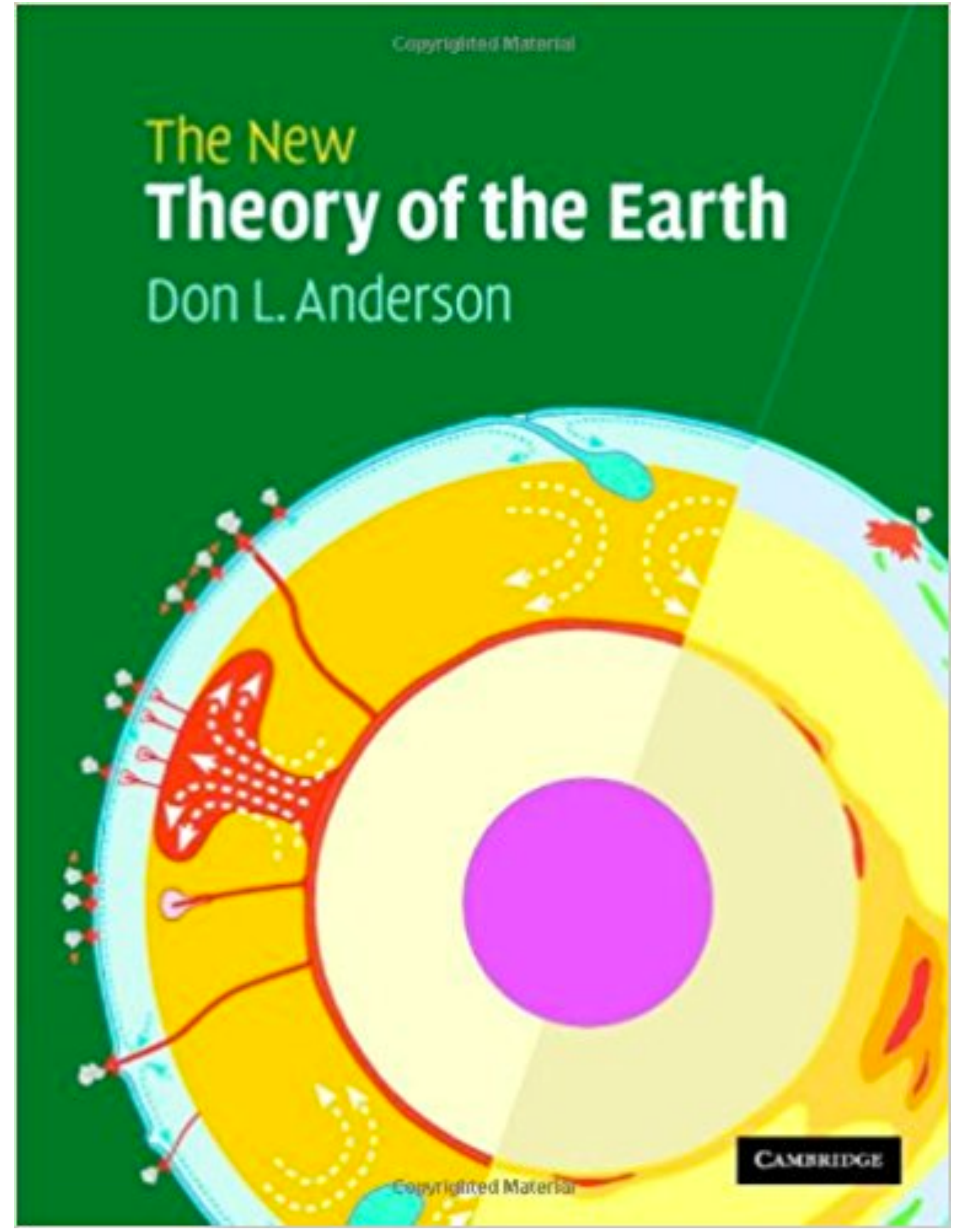
2. The concept of the model

An average Earth model, the subject of this work, is a mathematical abstraction. The lateral heterogeneity in the first few tens of kilometers is so large that an average model does not reflect the actual Earth structure at any point. In construction of the structure within the first 100 km we have adopted the concept of weighted average: assuming that oceanic crust covers two-thirds of the Earth's surface and that the average depth to the Moho is 11 km under oceans and 35 km under continents, we arrive at a figure of 19 km for the depth to the Moho for the average Earth. This is used as the trial starting value.

We recognize the following principal regions within the Earth:

(1) Ocean layer.
(2) Upper and lower crust.
(3) Region above the low velocity zone (LID), considered to be the main part of the seismic lithosphere. When we finally dropped the assumption of isotropy the distinction between LID and LVZ became less pronounced.
(4) Low velocity zone (LVZ).
(5) Region between low velocity zone and 400 km discontinuity.
(6) Transition zone spanning the region between the 400 and 670 km discontinuities.
(7) Lower mantle. In our work we found it necessary to subdivide this region into three parts connected by second-order discontinuities.
(8) Outer core.
(9) Inner core.





http://authors.library.caltech.edu/25018/1/TheoryoftheEarth.pdf

http://authors.library.caltech.edu/25038/104/New_Theory_of_the_Earth.pdf

Comparative planetology

Before the advent of space exploration, Earth scientists had a handicap almost unique in science: they had only one object to study. Compare this with the number of objects available to astronomers, particle physicists, biologists and sociologists. Earth theories had to be based almost entirely on evidence from Earth itself.

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Volume I

MAINLY MECHANICS, RADIATION AND HEAT

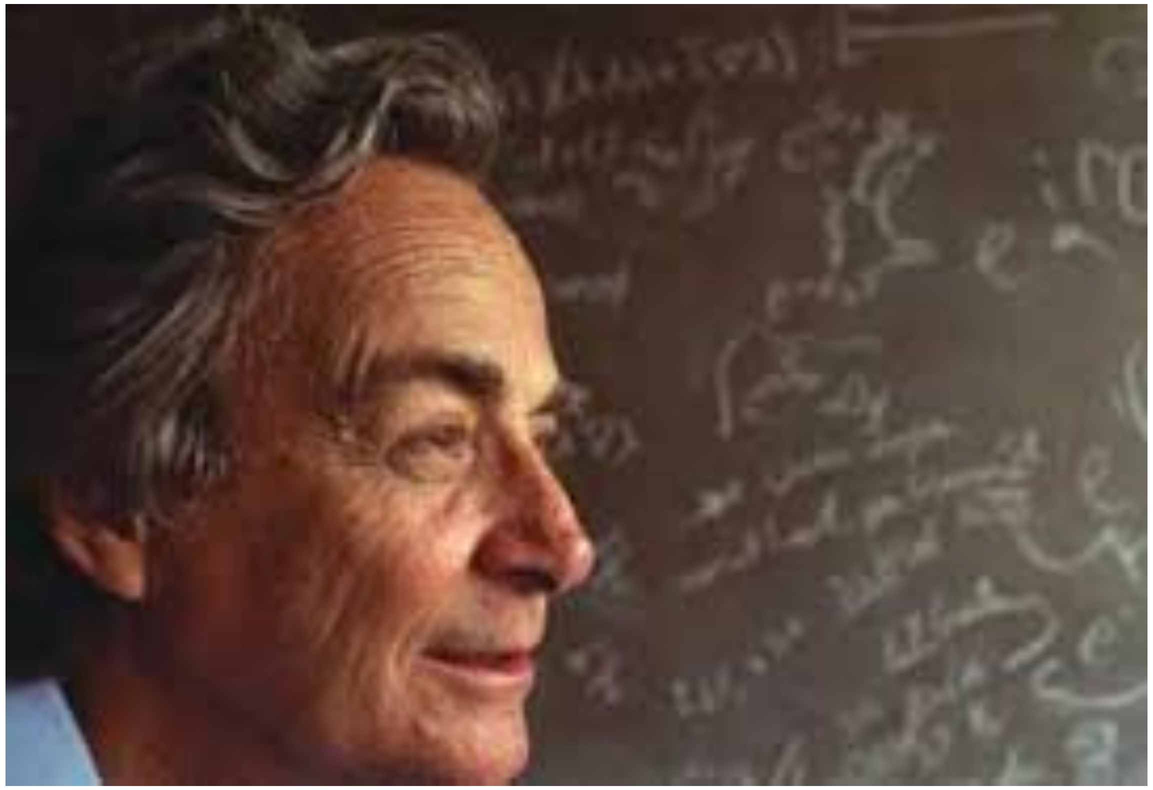
Volume II

MAINLY ELECTROMAGNETISM AND MATTER

Volume III

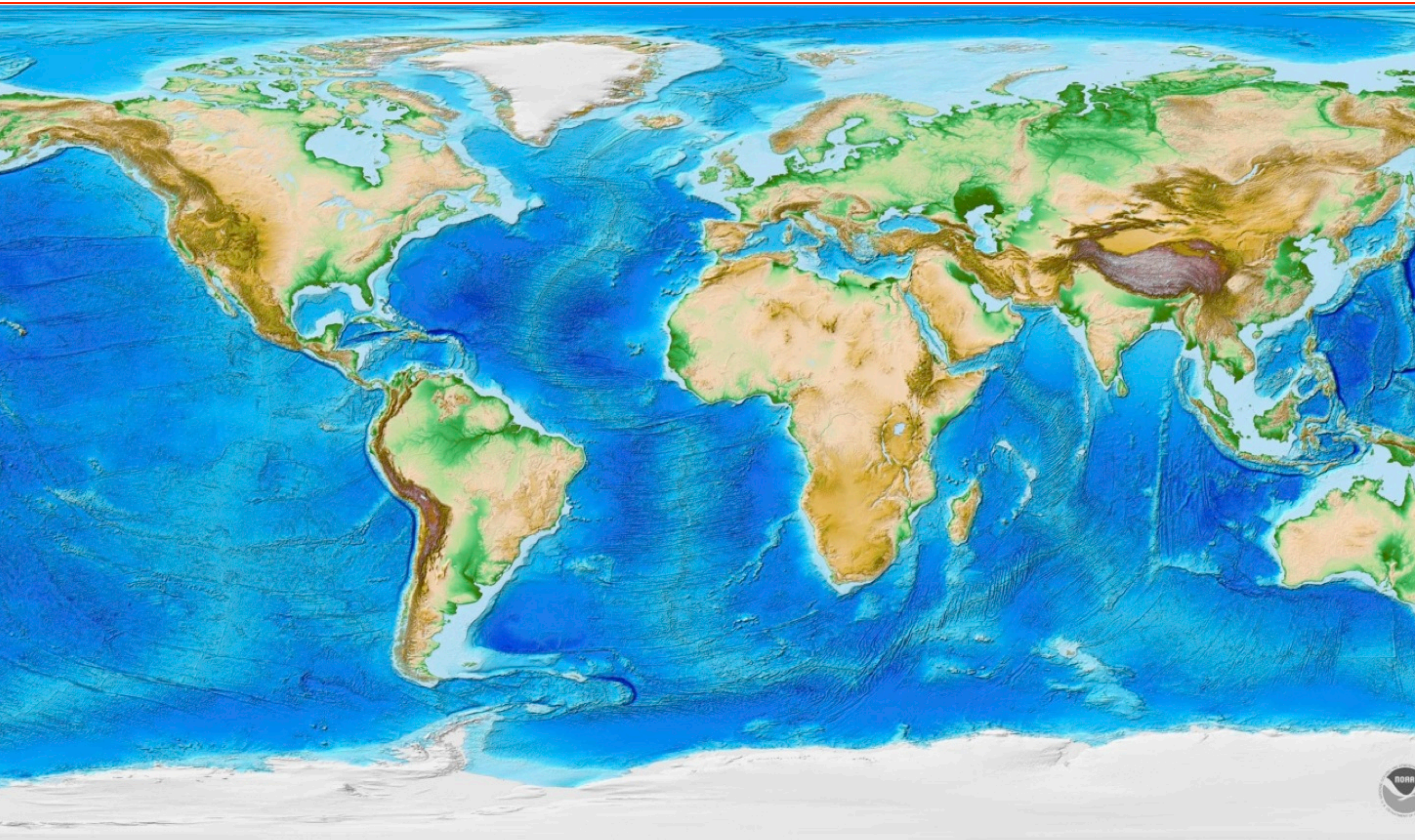
QUANTUM MECHANICS

A dinâmica interna da Terra

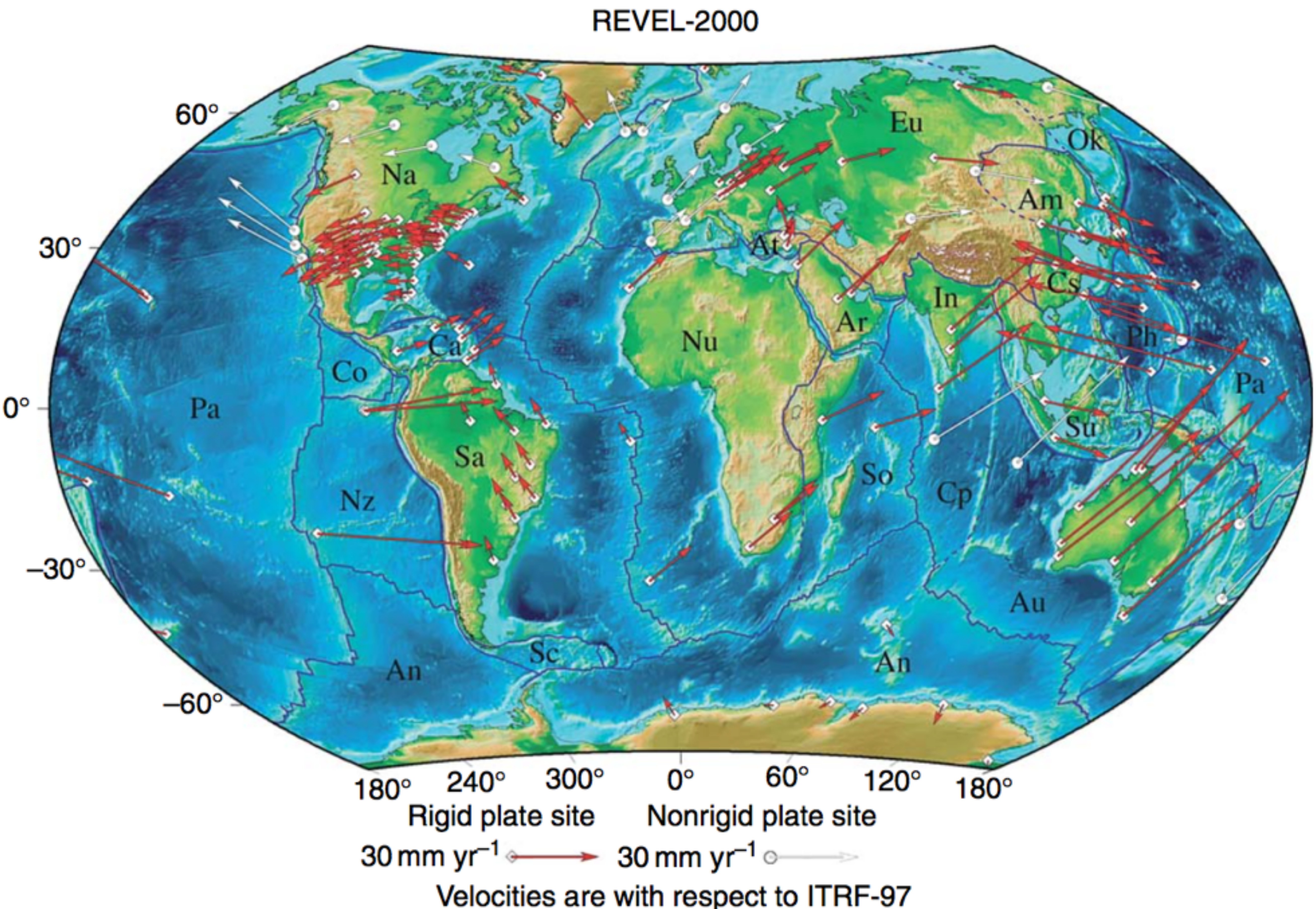


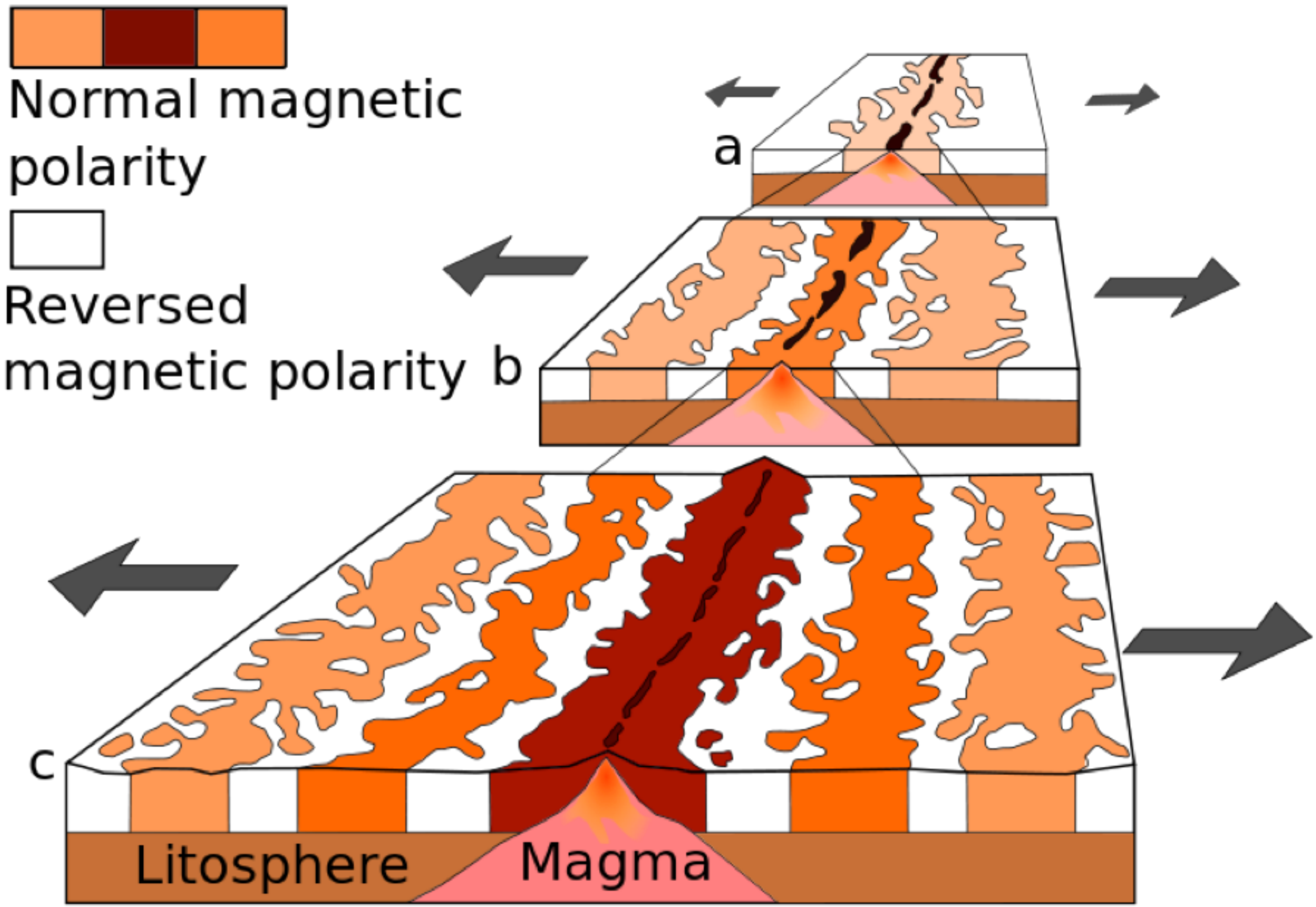
"We do much less well with the Earth than we do with the conditions of matter in the stars."
Richard Feynman
(1962)

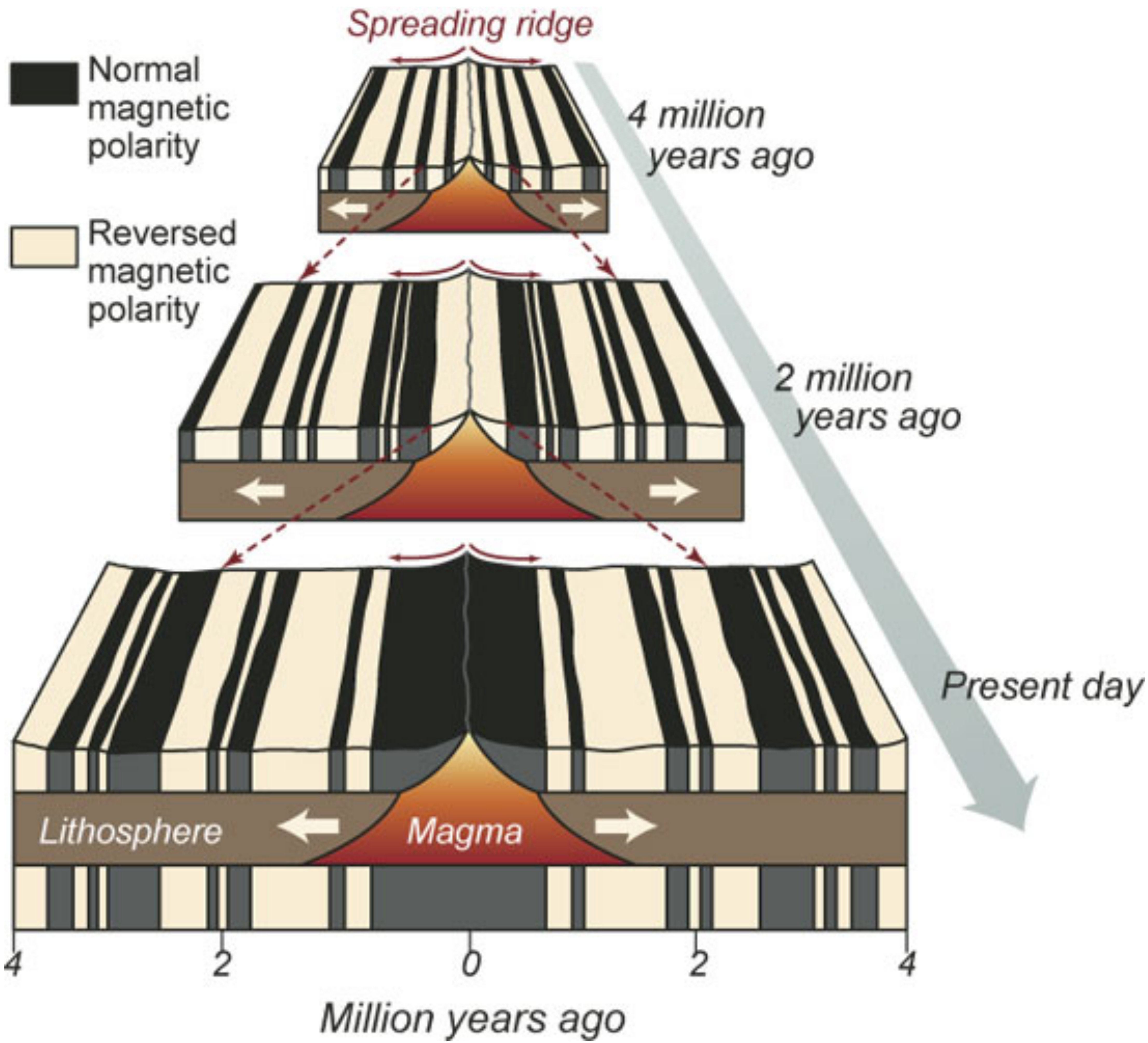
Tectônica de placas

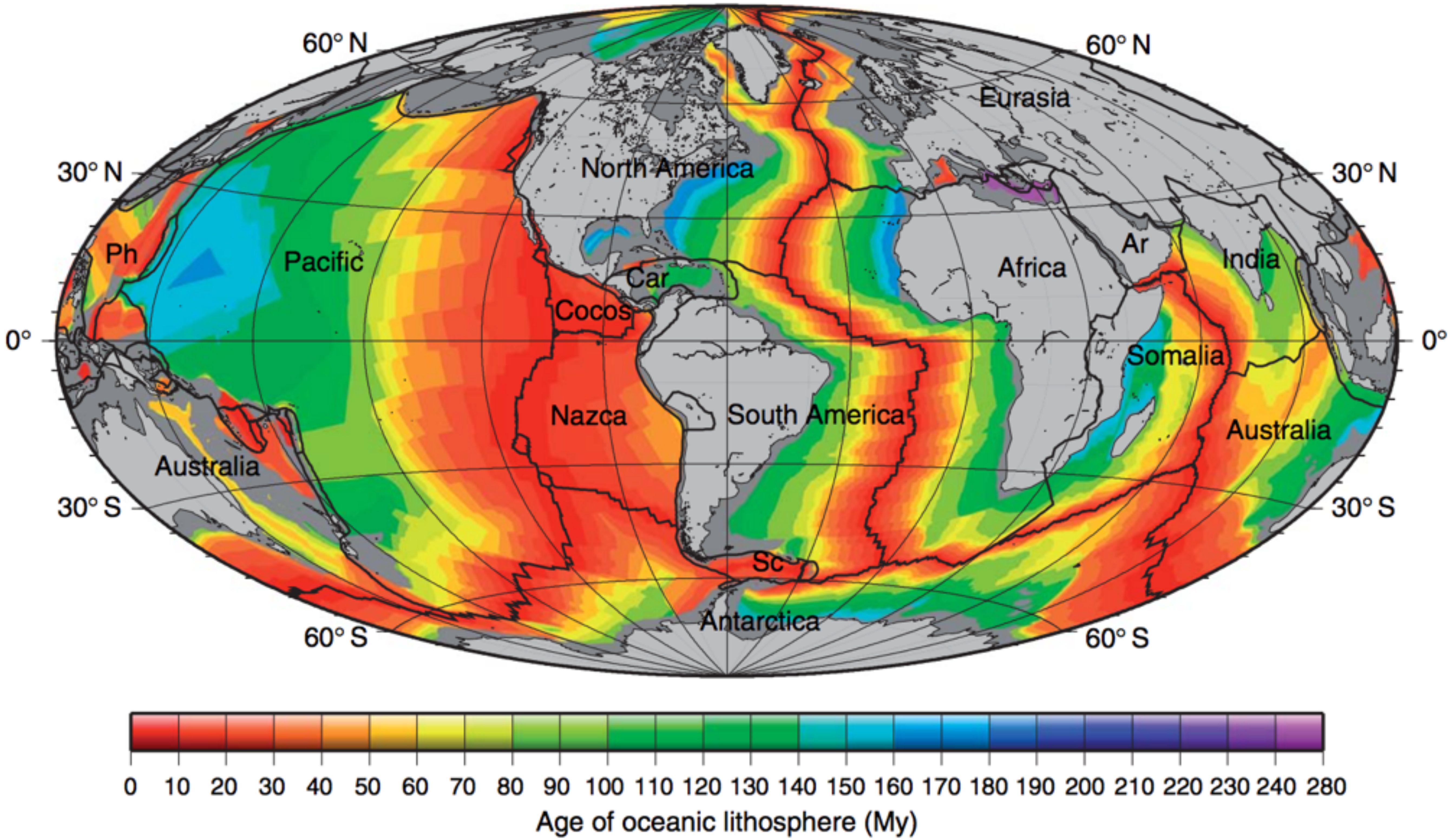


Tectônica de placas




Normal magnetic polarity
Reversed magnetic polarity
a
b
c
Litosphere
Magma


Spreading ridge
Normal magnetic polarity
Reversed magnetic polarity
4 million years ago
2 million years ago
Present day
Lithosphere
Magma
4
2
0
2
4
Million years ago



Jaupart & Mareschal (2007)

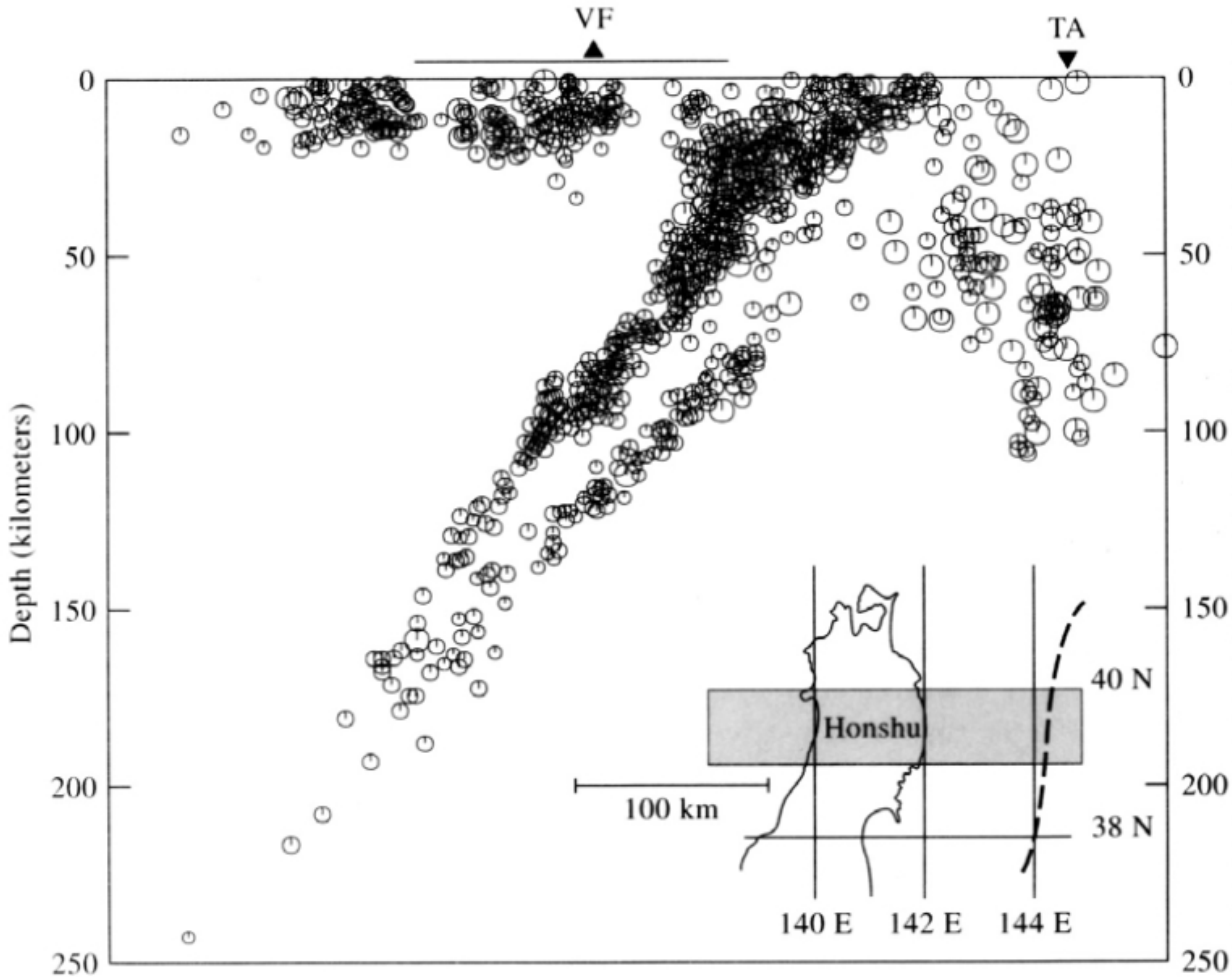
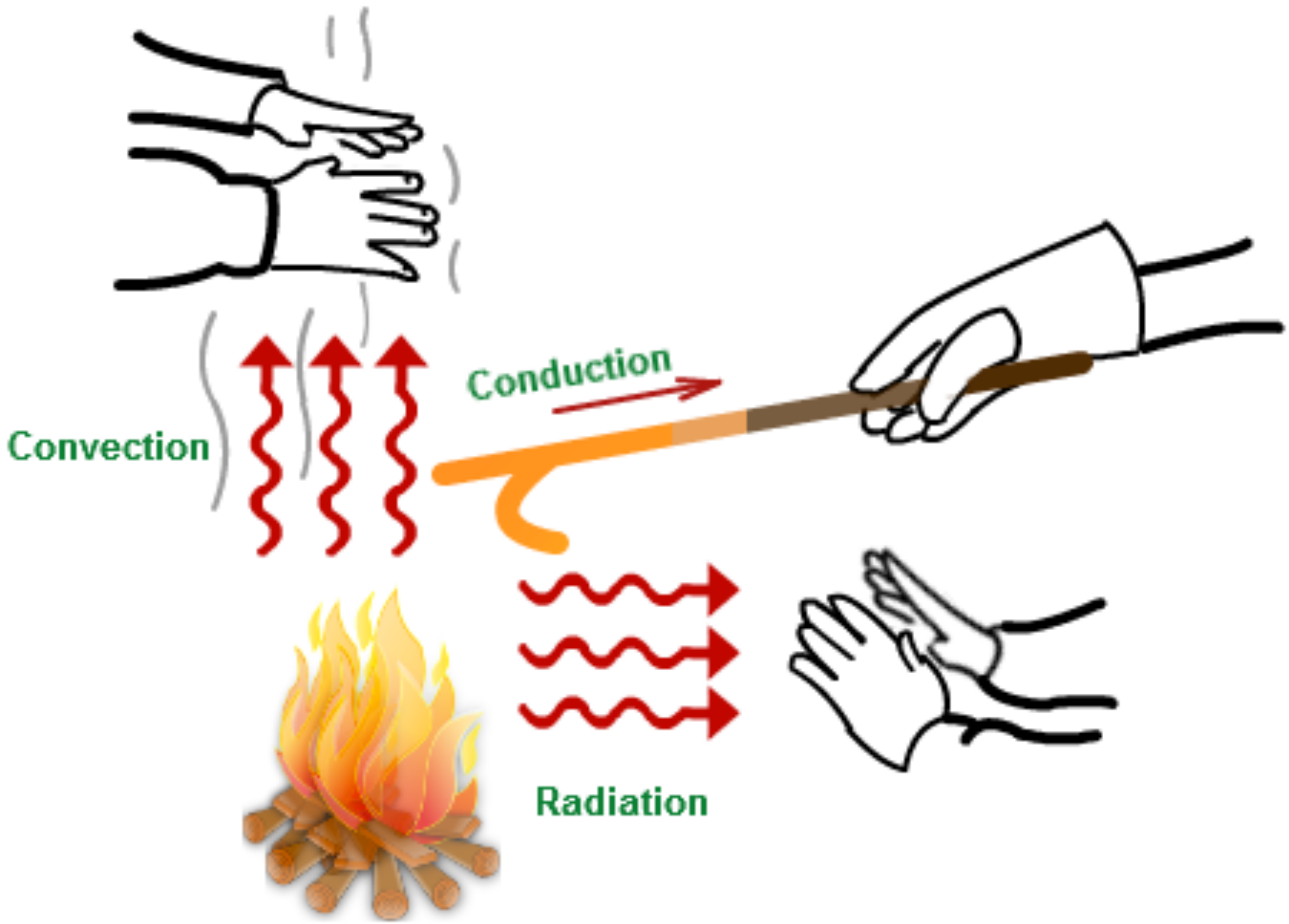
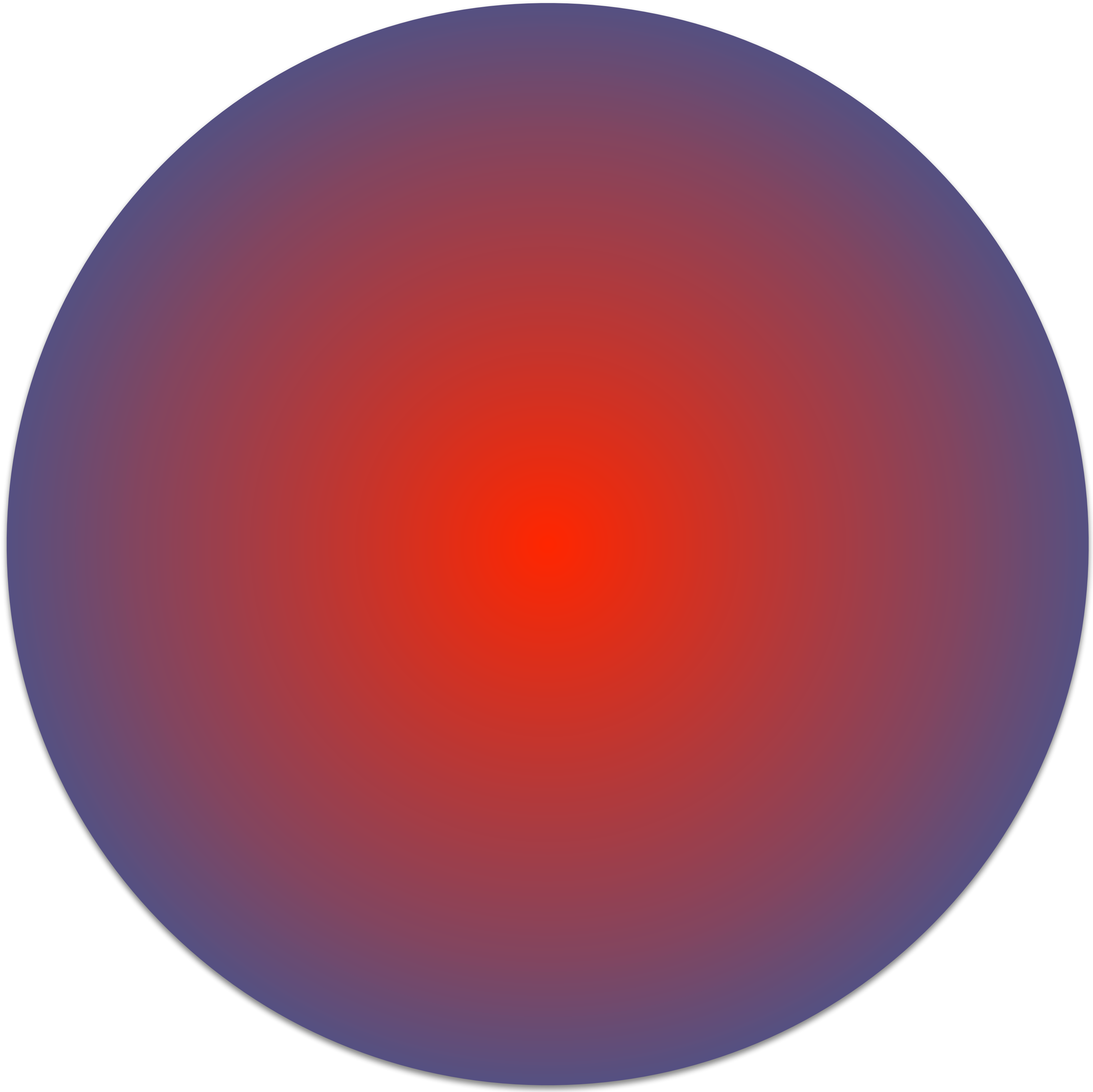


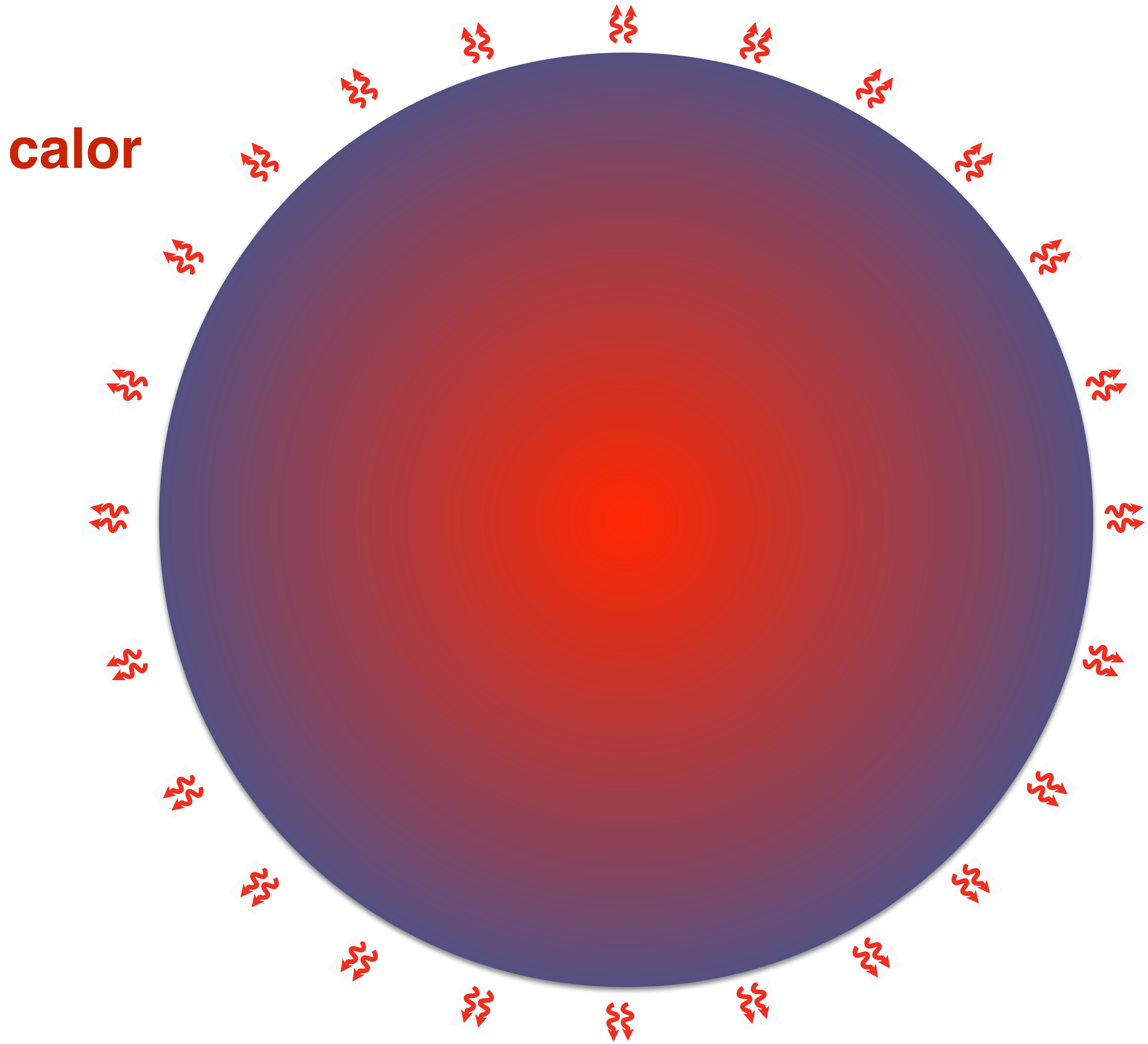
Figure 2.20. Double Benioff zone marking subduction at the Japan arc. Circles are foci of earthquakes recorded in 1975 and 1976. VF – volcanic front, TA – Japan Trench axis. After Hasegawa et al. (1978b). Redrawn from Bolt (1993).

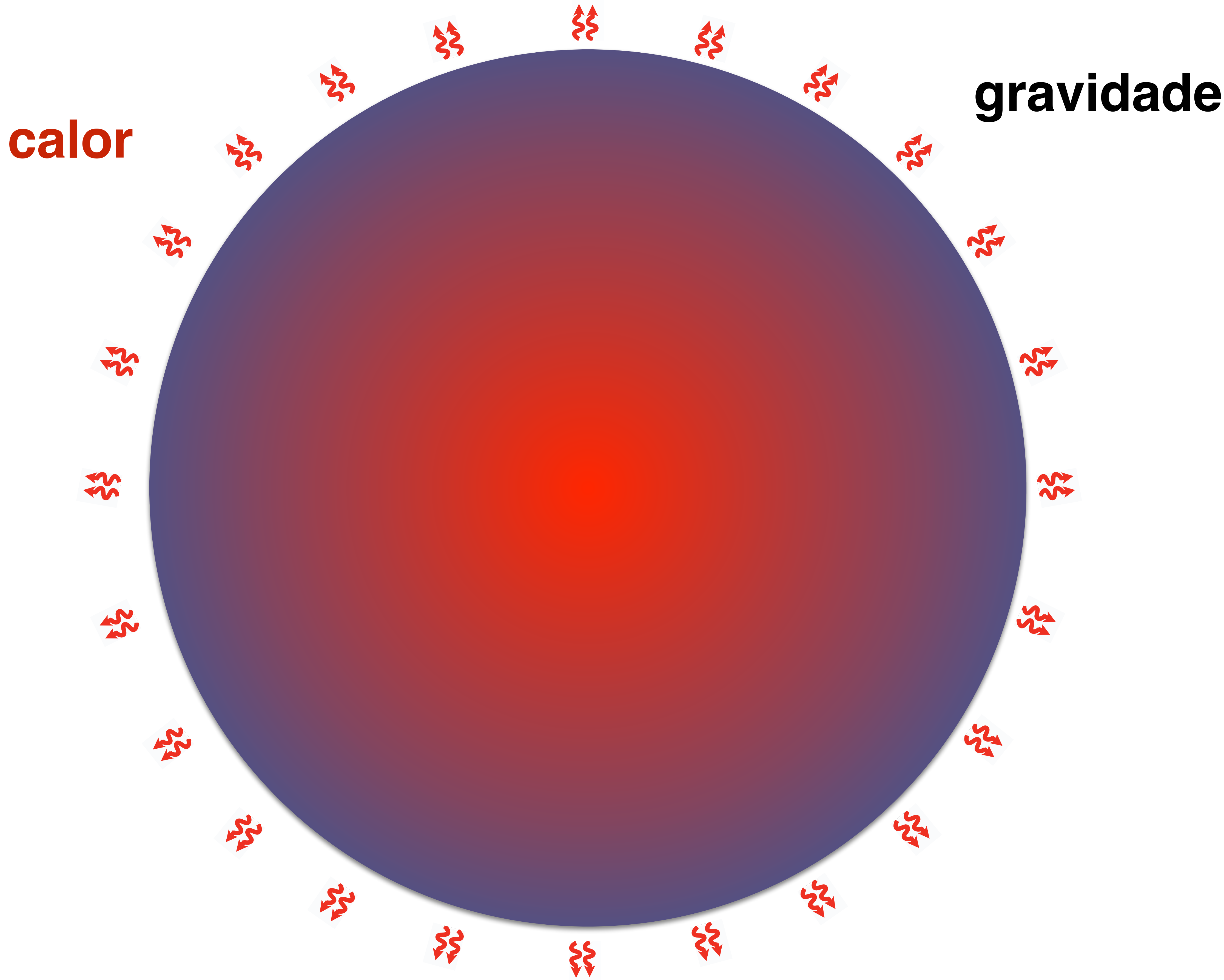
Qual é o motor da tectônica de placas?

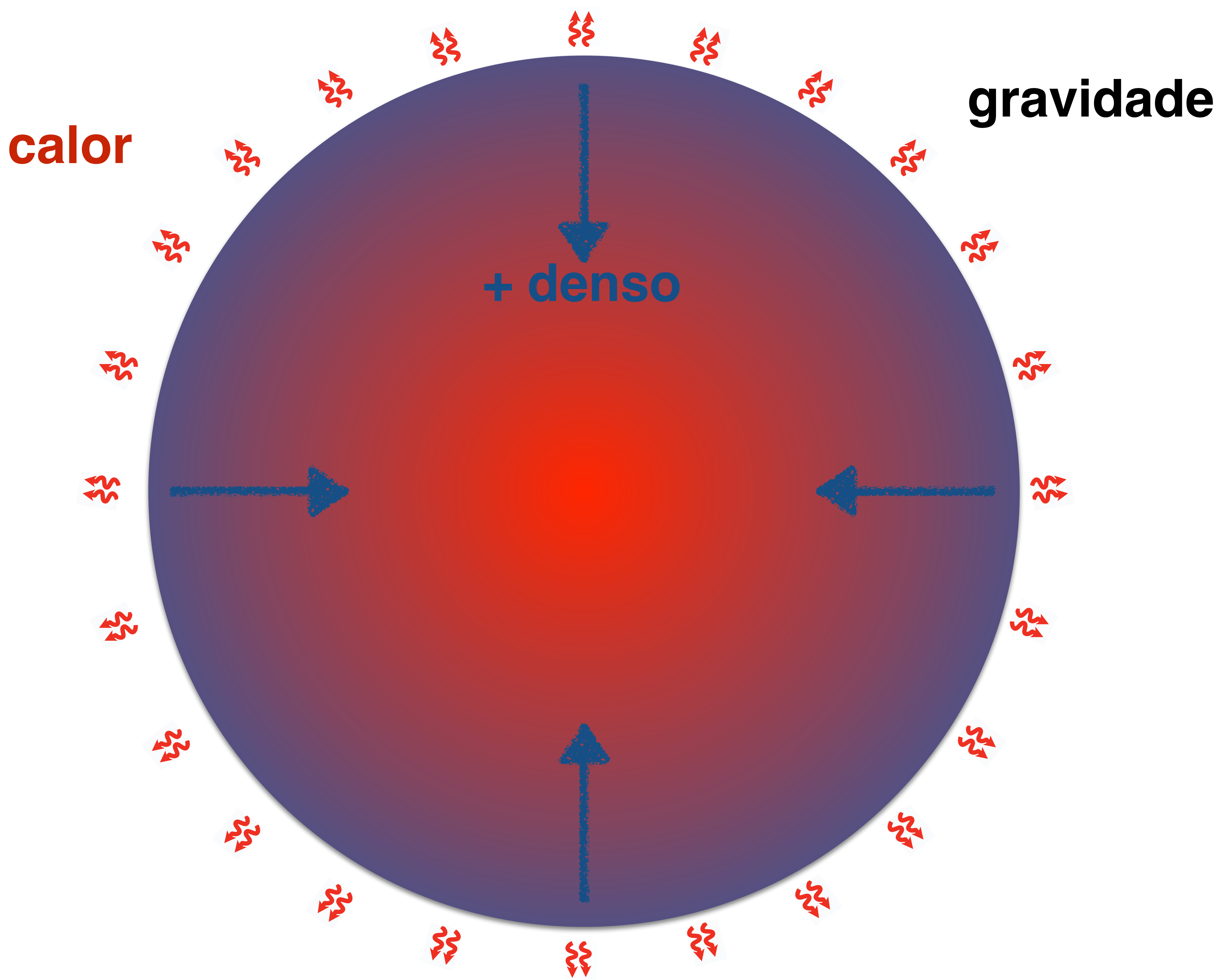
Formas de transporte de calor

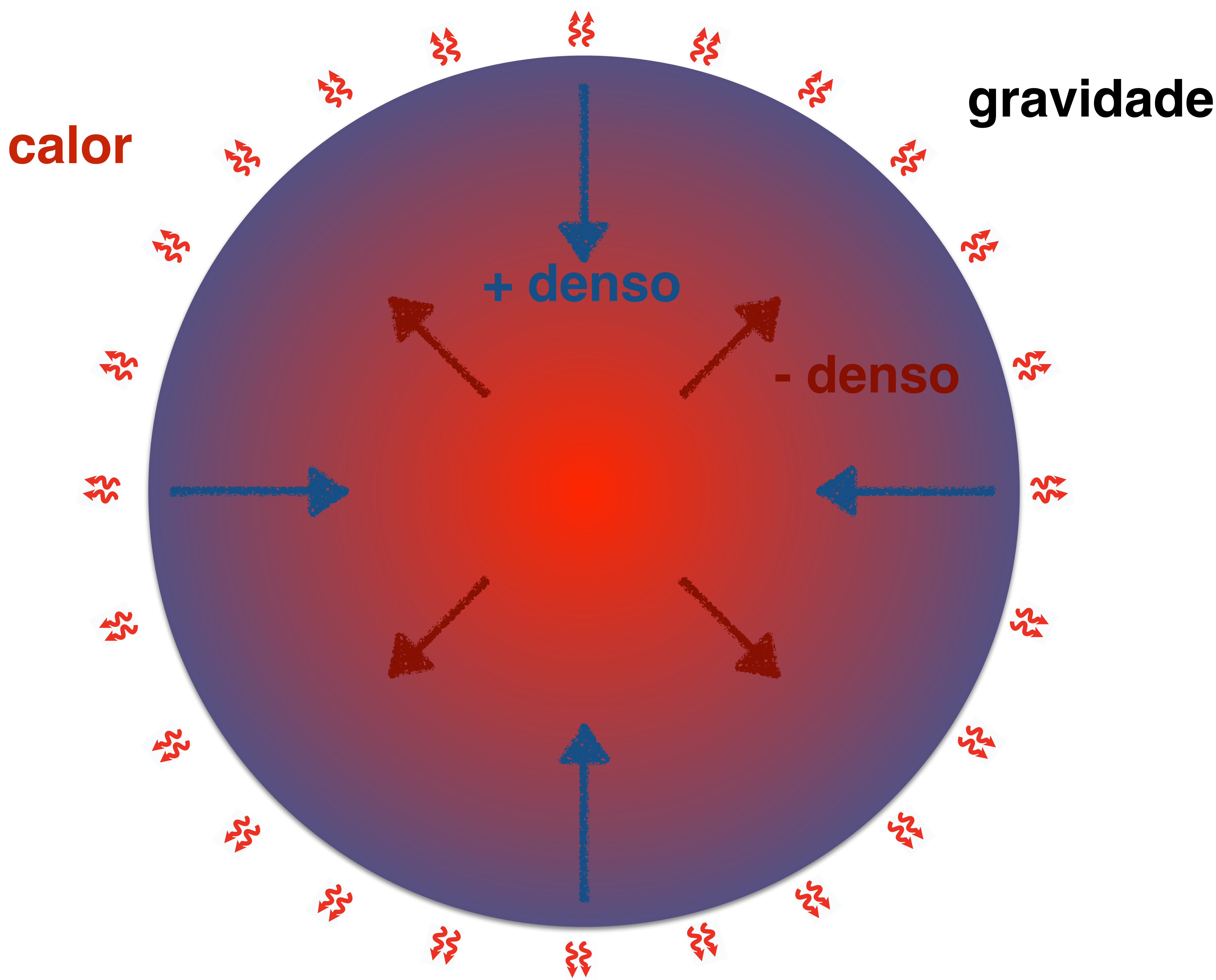


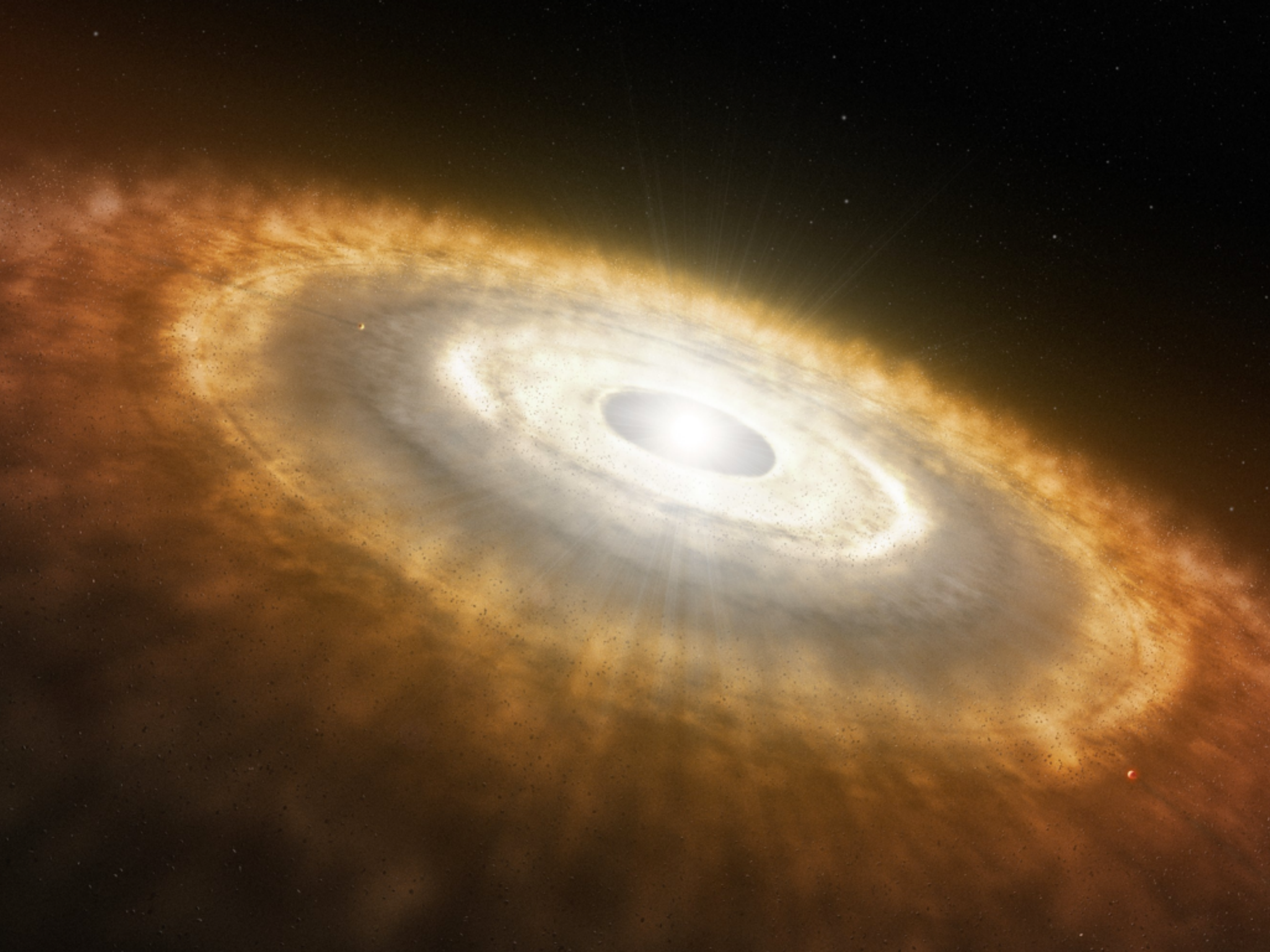



calor

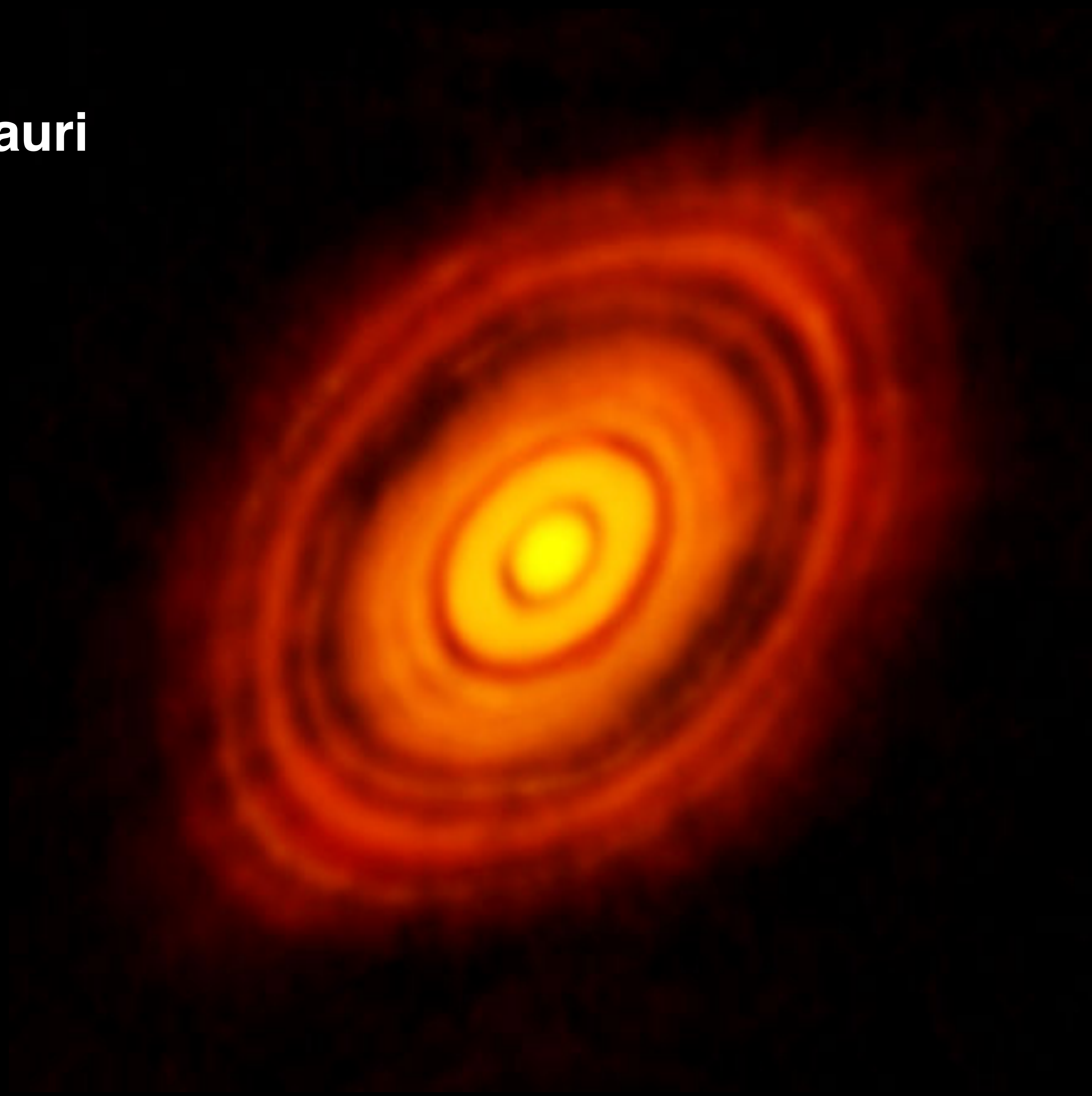

calor
gravidade

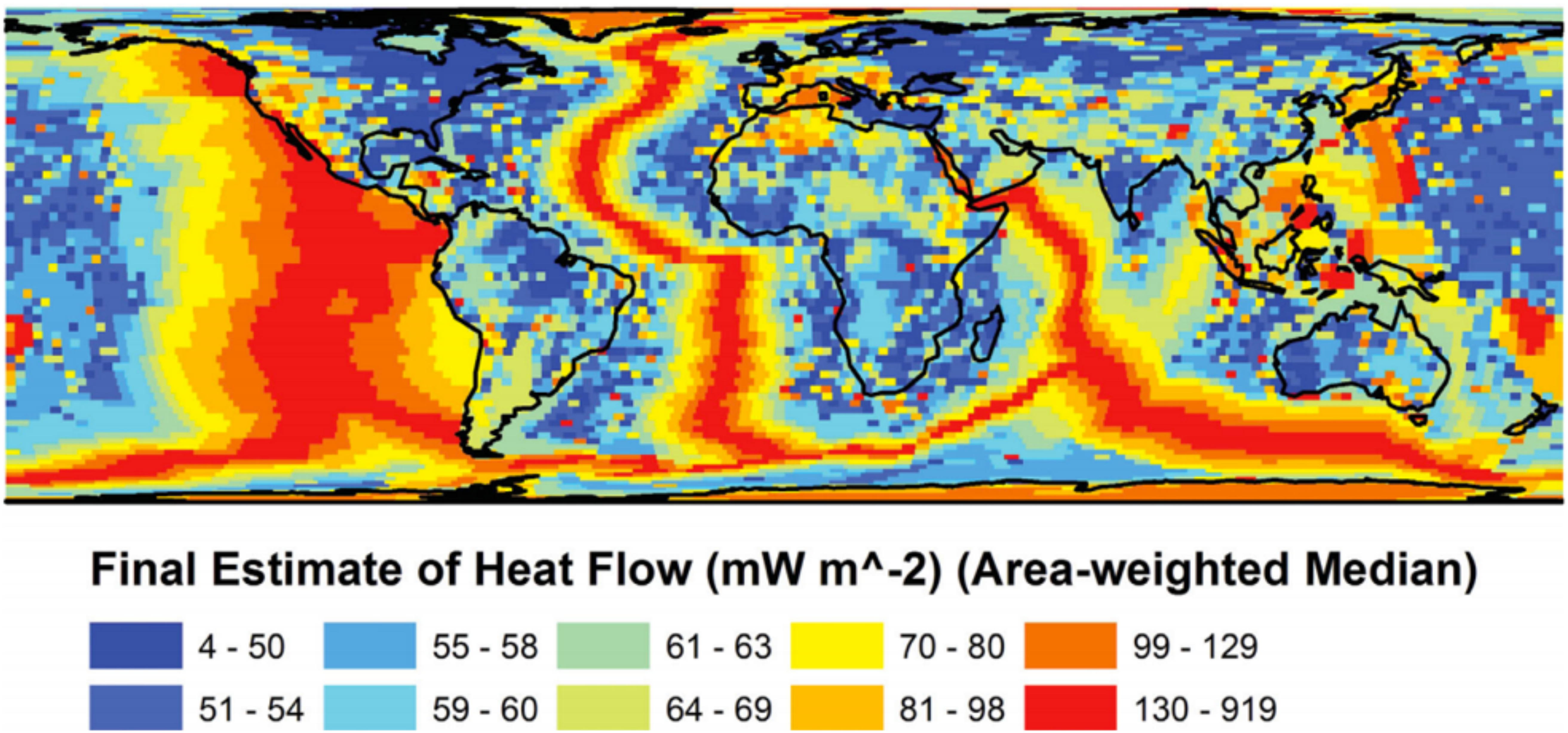

calor
gravidade
+ denso


calor
gravidade
+ denso
- denso

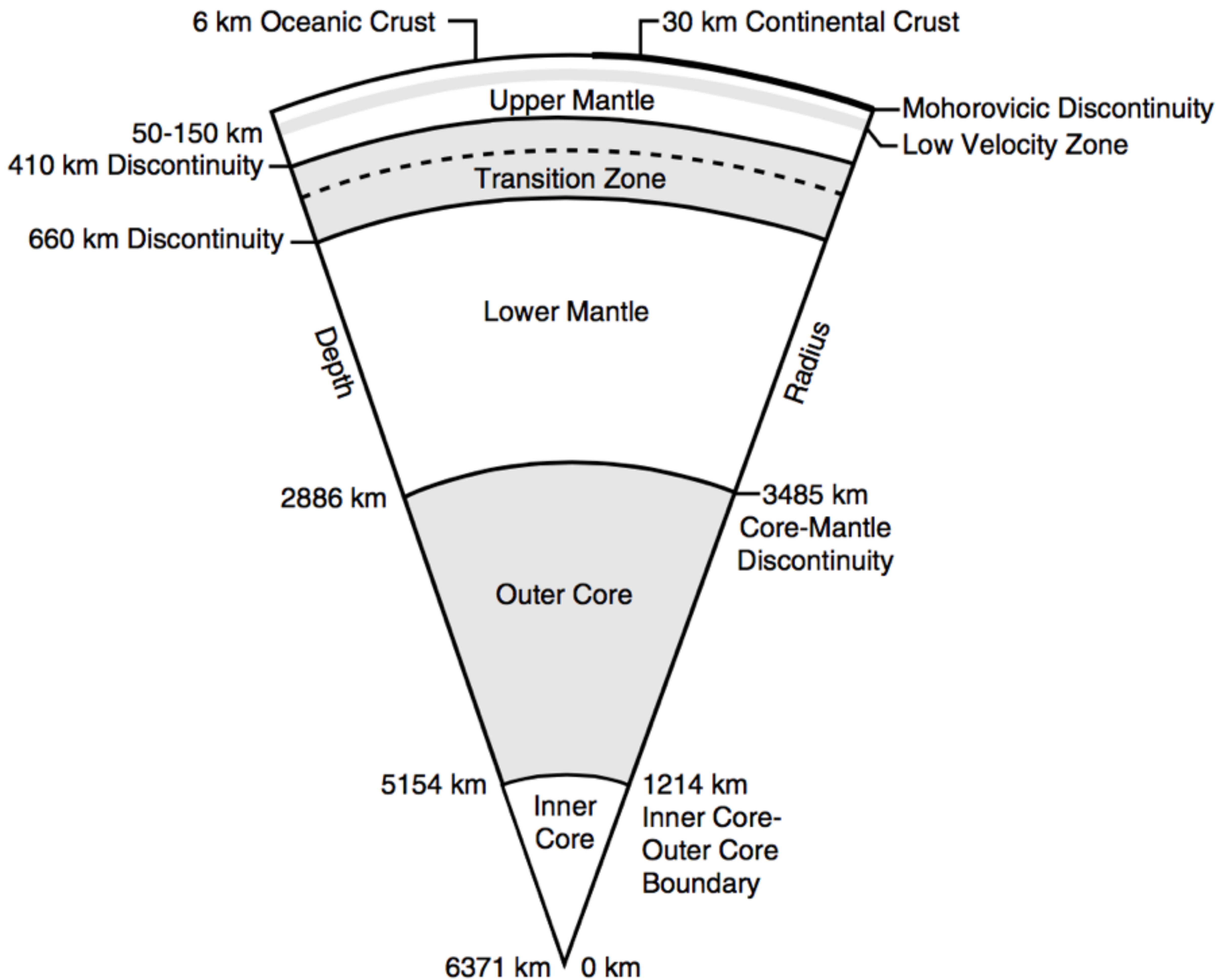


HL Tauri

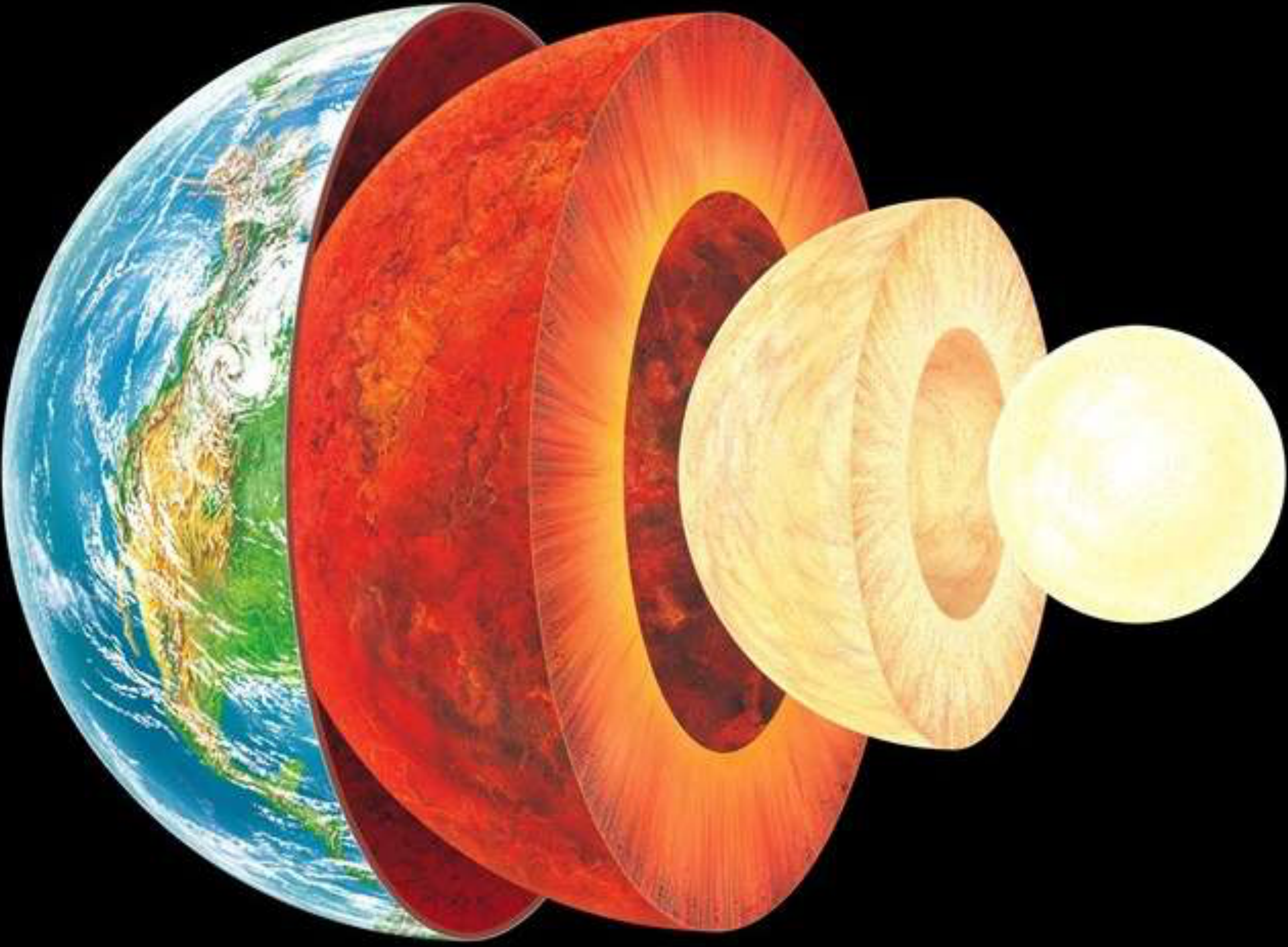



Final Estimate of Heat Flow (mW m^-2) (Area-weighted Median)
4 - 50
51 - 54
55 - 58
59 - 60
61 - 63
64 - 69
70 - 80
81 - 98
99 - 129
130 - 919

Davies (2013)

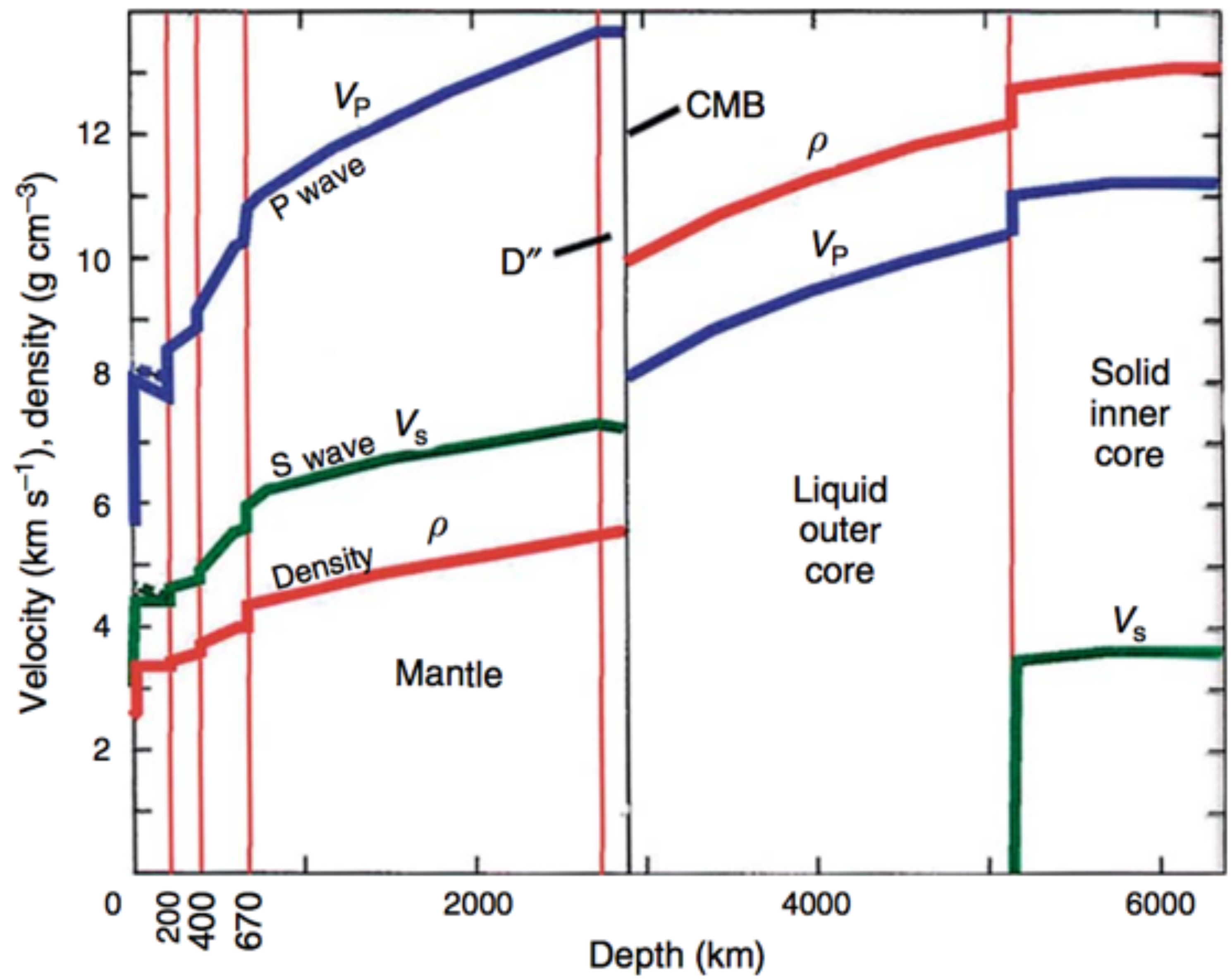


6 km Oceanic Crust
30 km Continental Crust
Upper Mantle
Mohorovicic Discontinuity
Low Velocity Zone
50-150 km
410 km Discontinuity
Transition Zone
660 km Discontinuity
Lower Mantle
Depth
Radius
2886 km
3485 km
Core-Mantle
Discontinuity
Outer Core
5154 km
1214 km
Inner Core-
Outer Core
Boundary
Inner
Core
6371 km
0 km



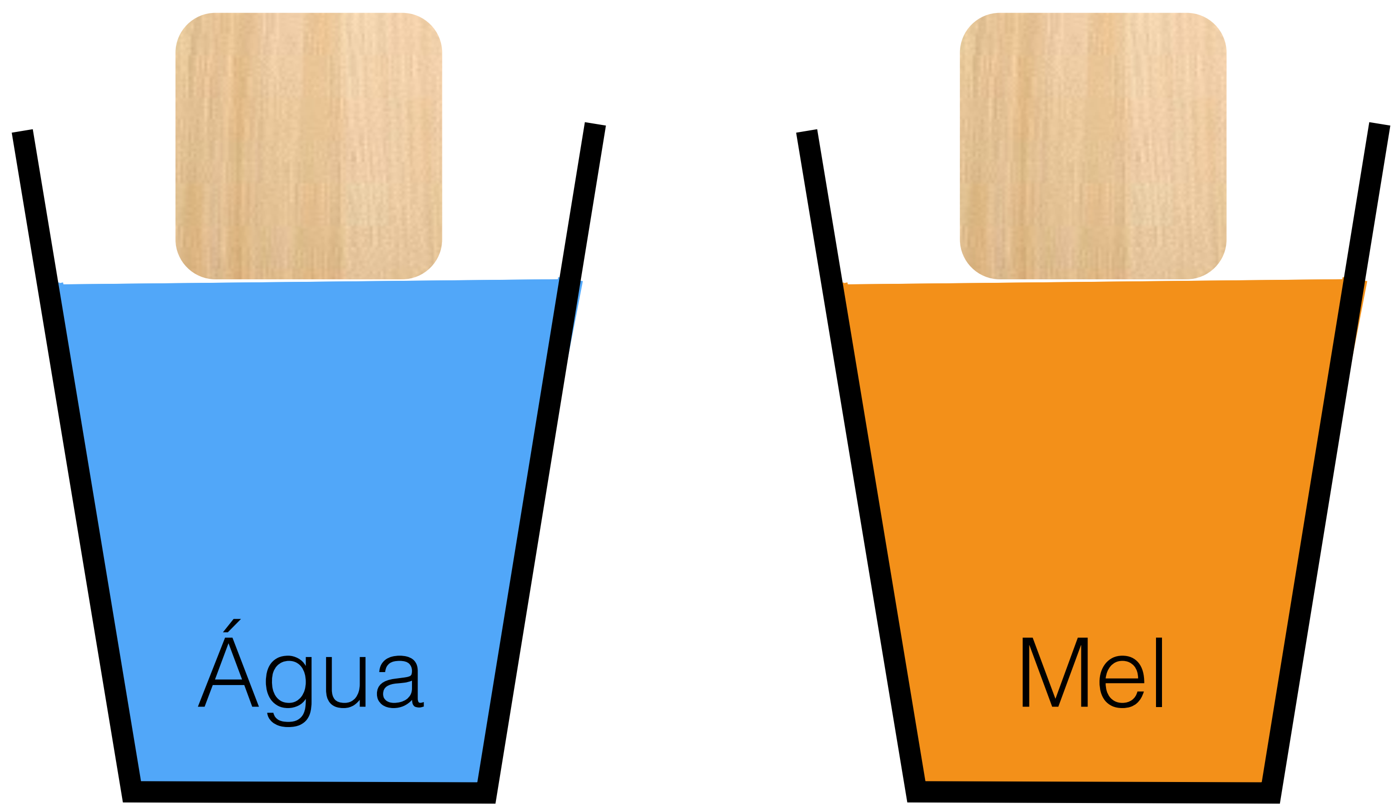
O manto é sólido!

manto **núcleo ext.** **núcleo int.**



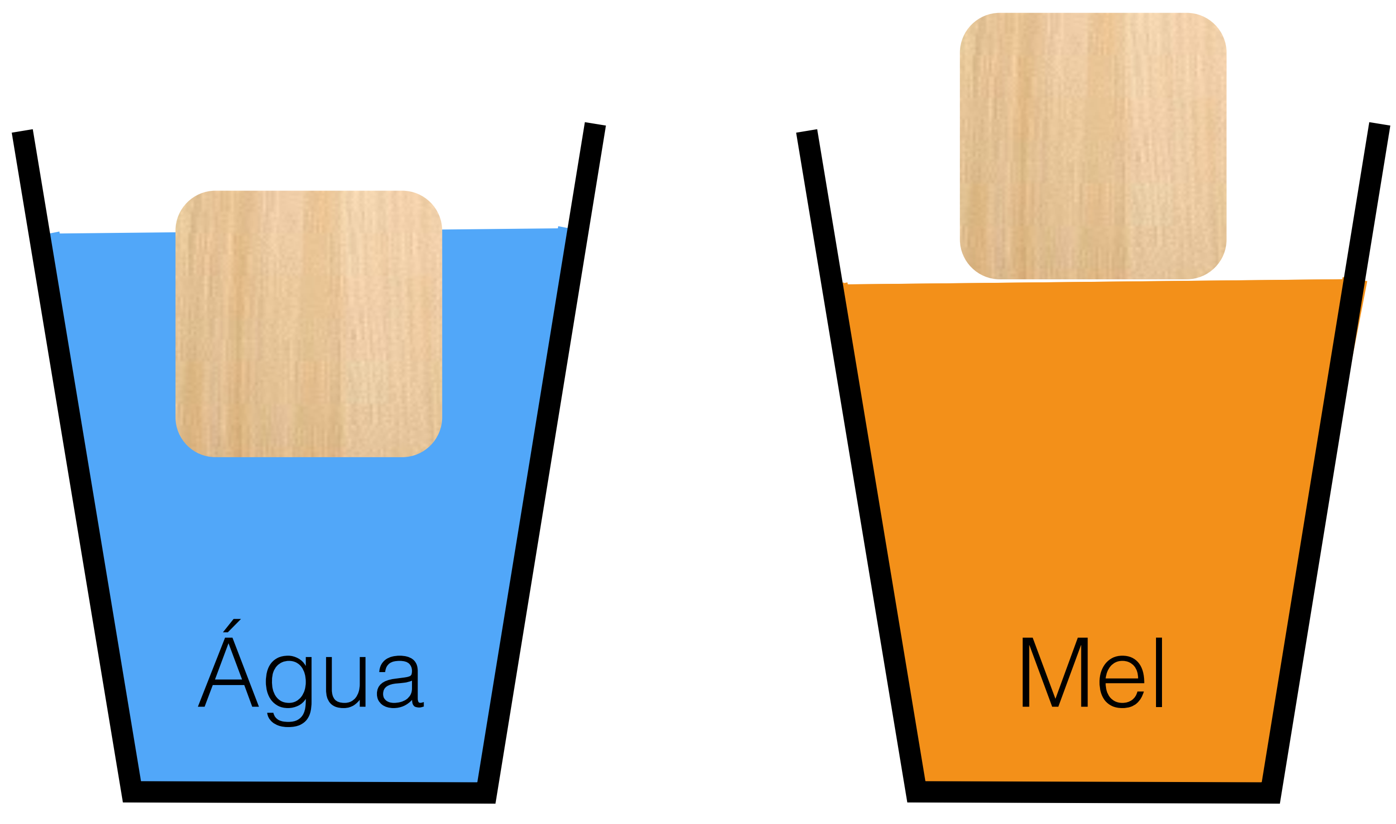
(Dziewonski & Romanowicz, 2007)

Tempo para restaurar o equilíbrio



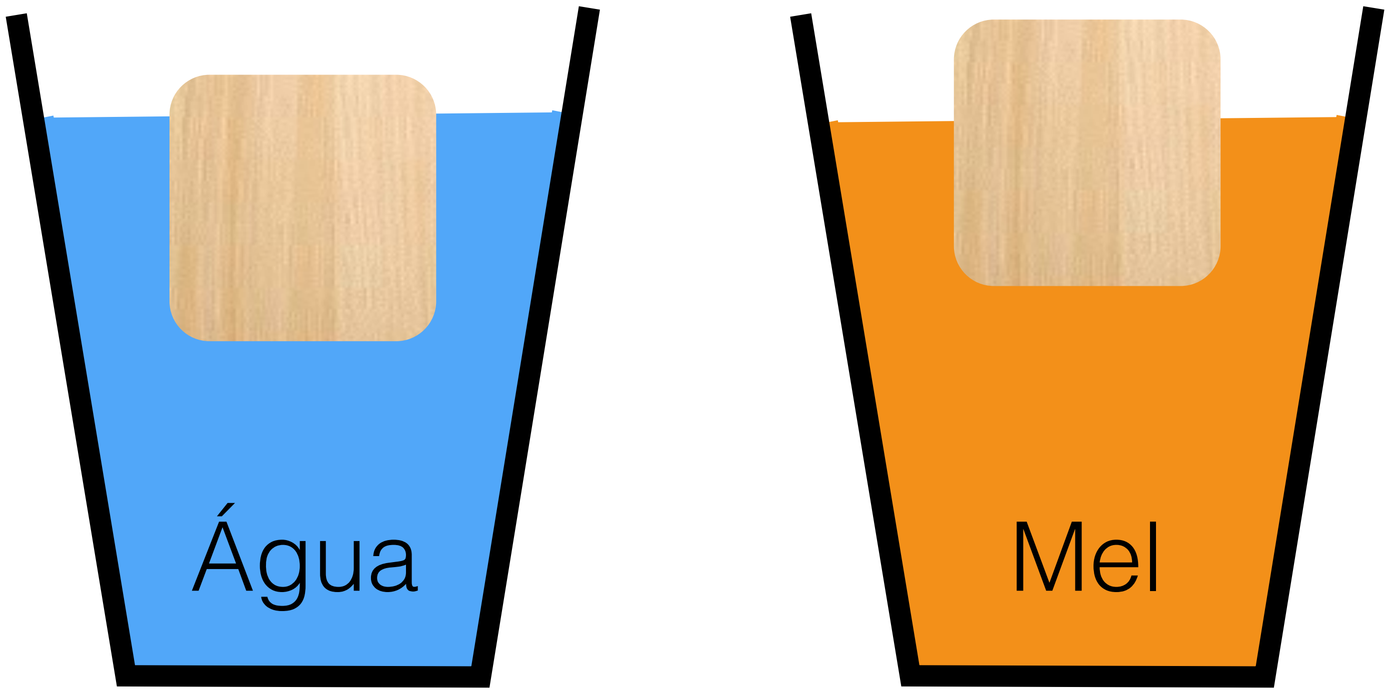
O mel é mais viscoso que a água

Tempo para restaurar o equilíbrio



O mel é mais viscoso que a água

Tempo para restaurar o equilíbrio



O mel é mais viscoso que a água

Viscosidade de Fluidos

Viscosidade de Fluidos

- Água 10^{-3} Pa s

Viscosidade de Fluidos

• Água	10^{-3} Pa s
• Mel	2 - 10 Pa s

Viscosidade de Fluidos

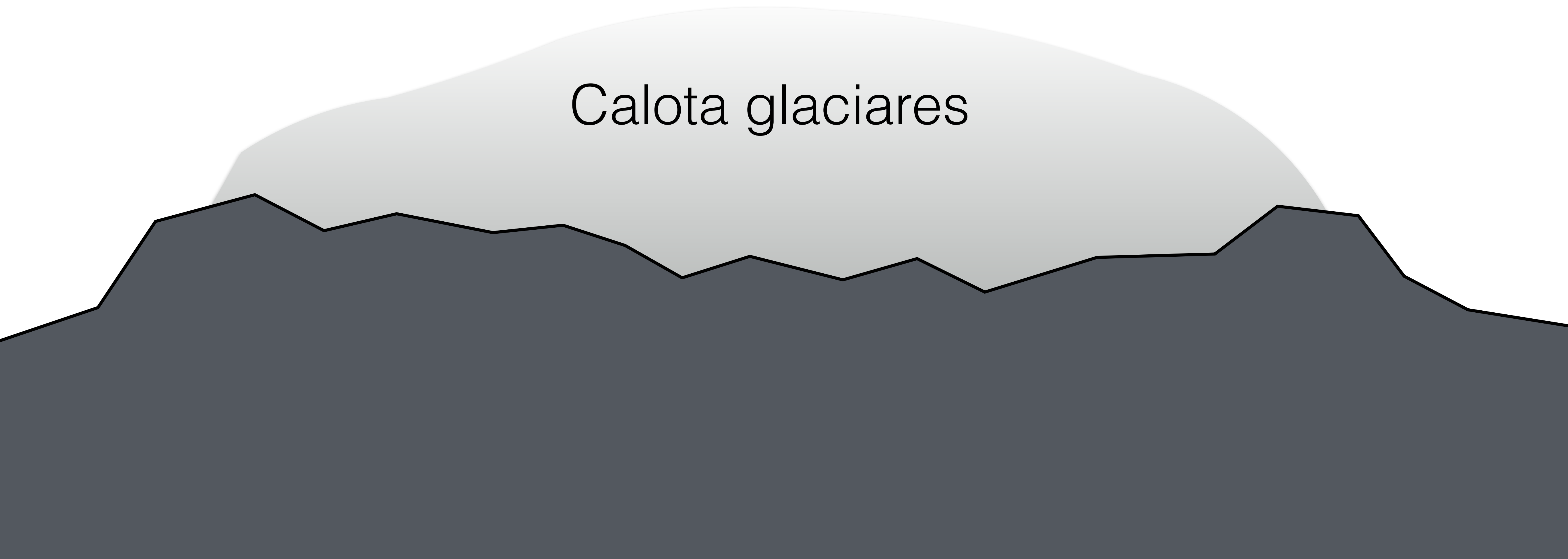
- Água 10^{-3} Pa s
- Mel 2 - 10 Pa s
- Vidro derretido 10^{1}-10^{3} Pa s

Viscosidade de Fluidos

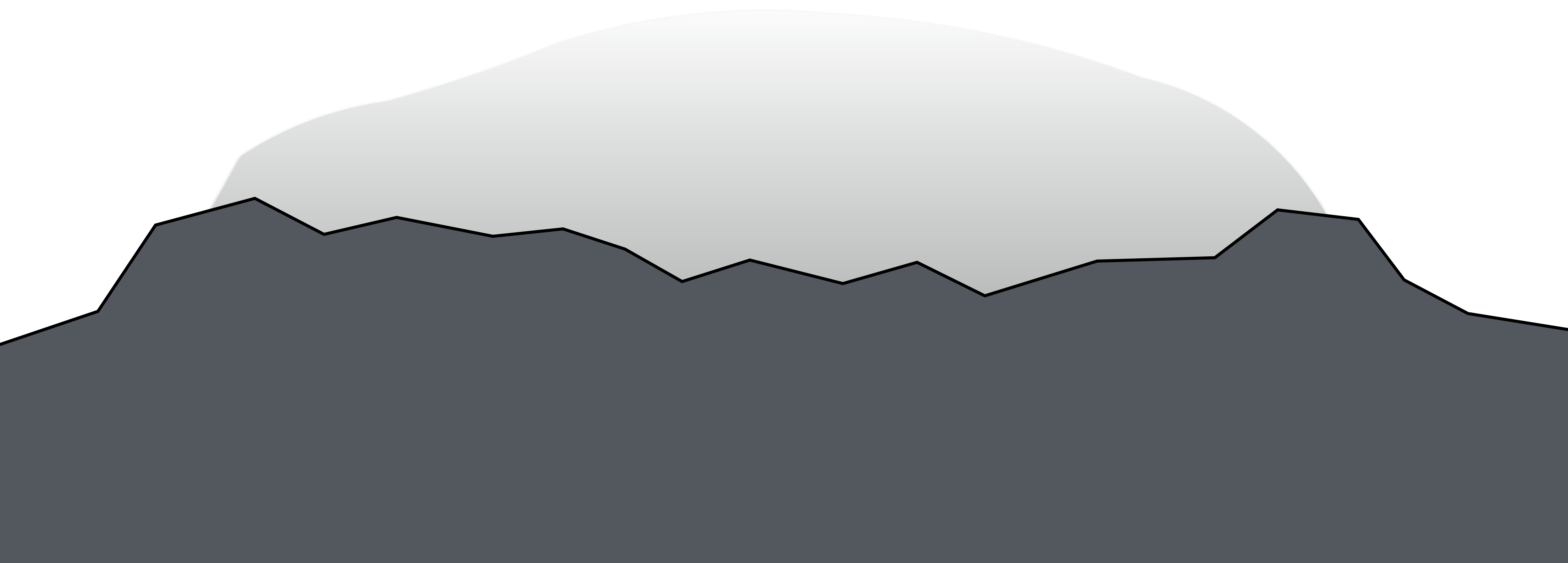



- Água 10^{-3} Pa s
- Mel 2 - 10 Pa s
- Vidro derretido 10^{1}-10^{3} Pa s
- Piche 10^{8}-10^{9} Pa s

Ajuste pós-glacial



Ajuste pós-glacial

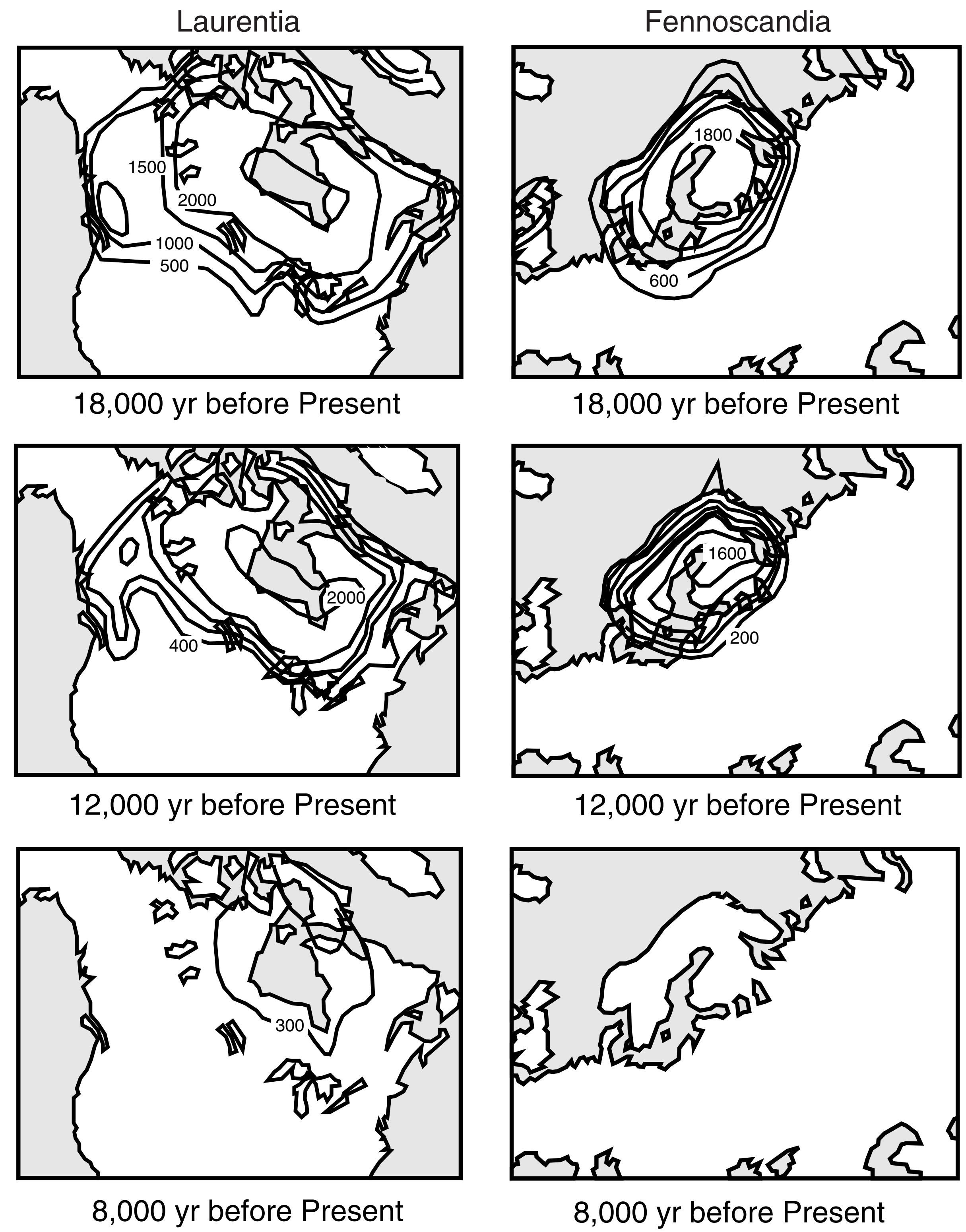


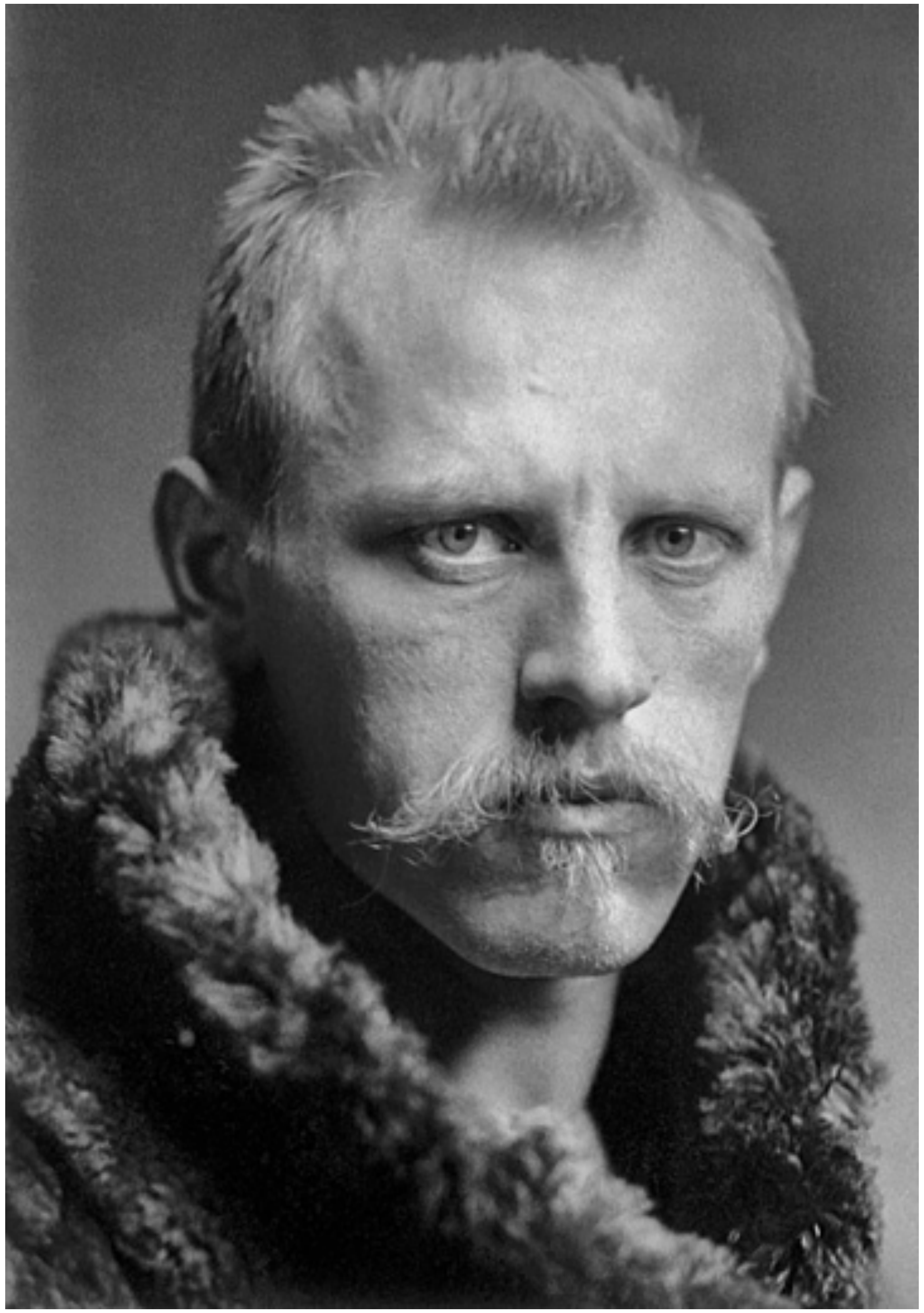
Ajuste pós-glacial

Ajuste pós-glacial

Ajuste pós-glacial

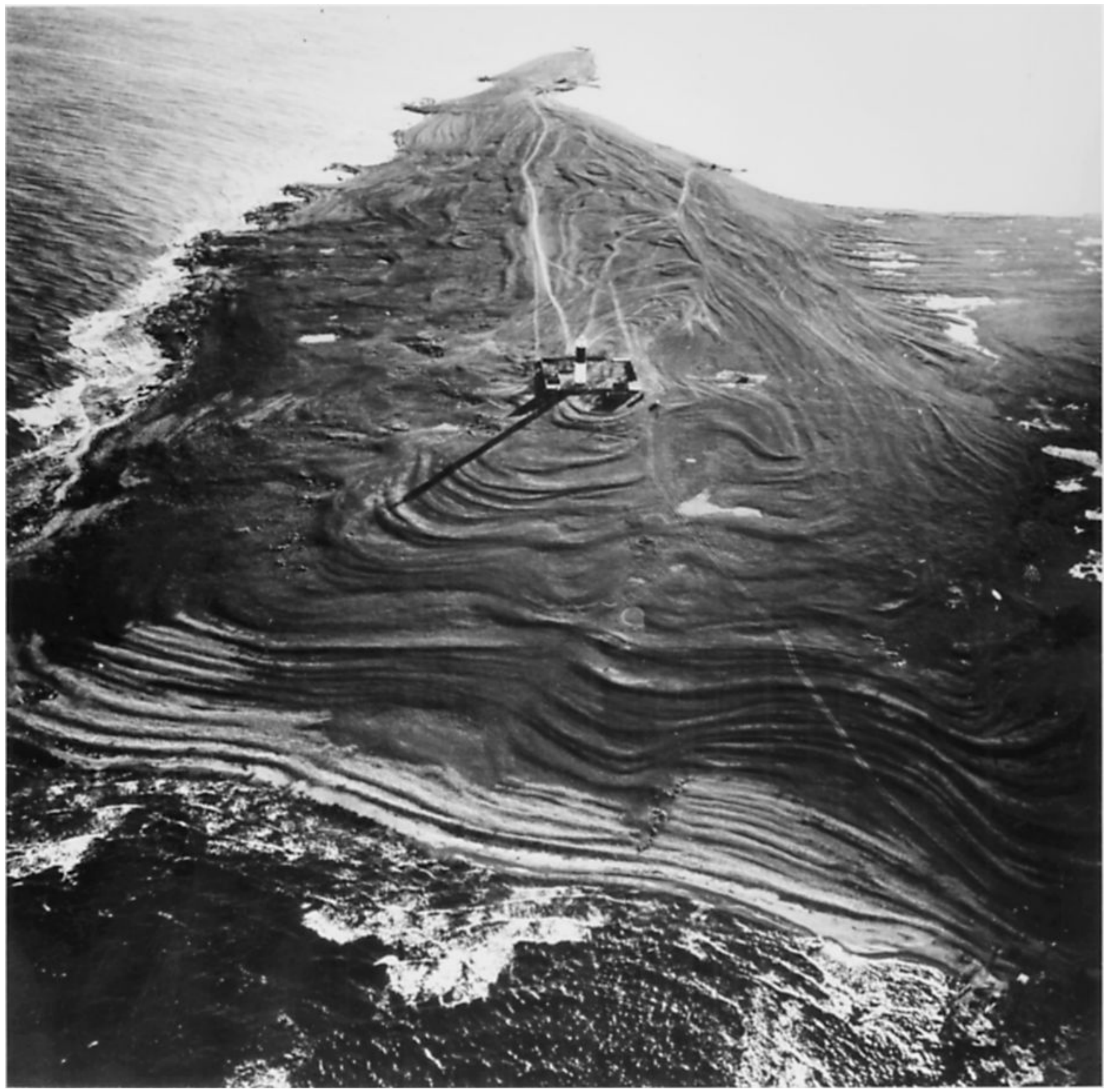
Ajuste pós-glacial



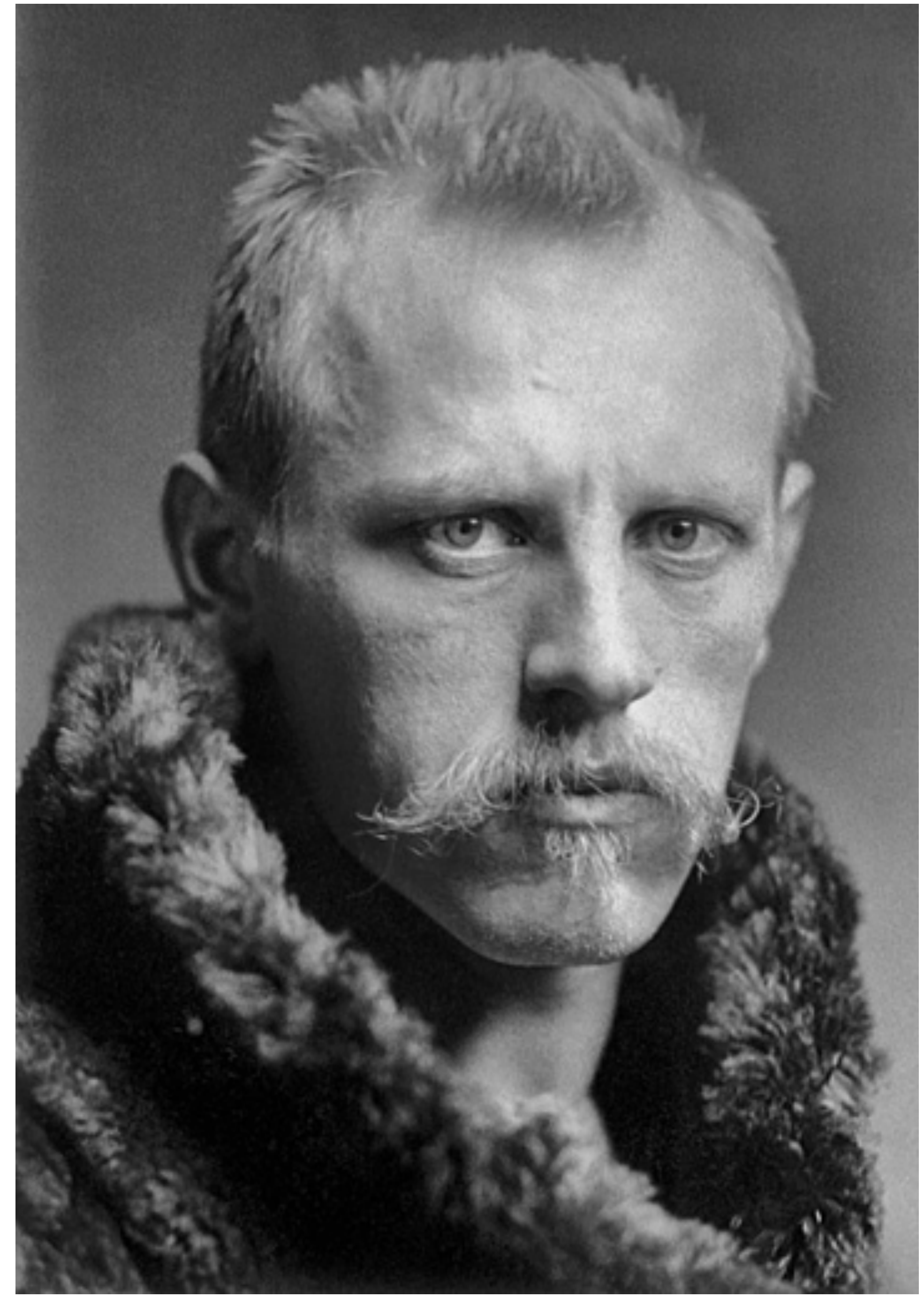


Fridtjof Nansen

Östergransholm, Eastern Gotland,



(Turcotte & Schubert,



Fridtjof Nansen

Praias soerguidas

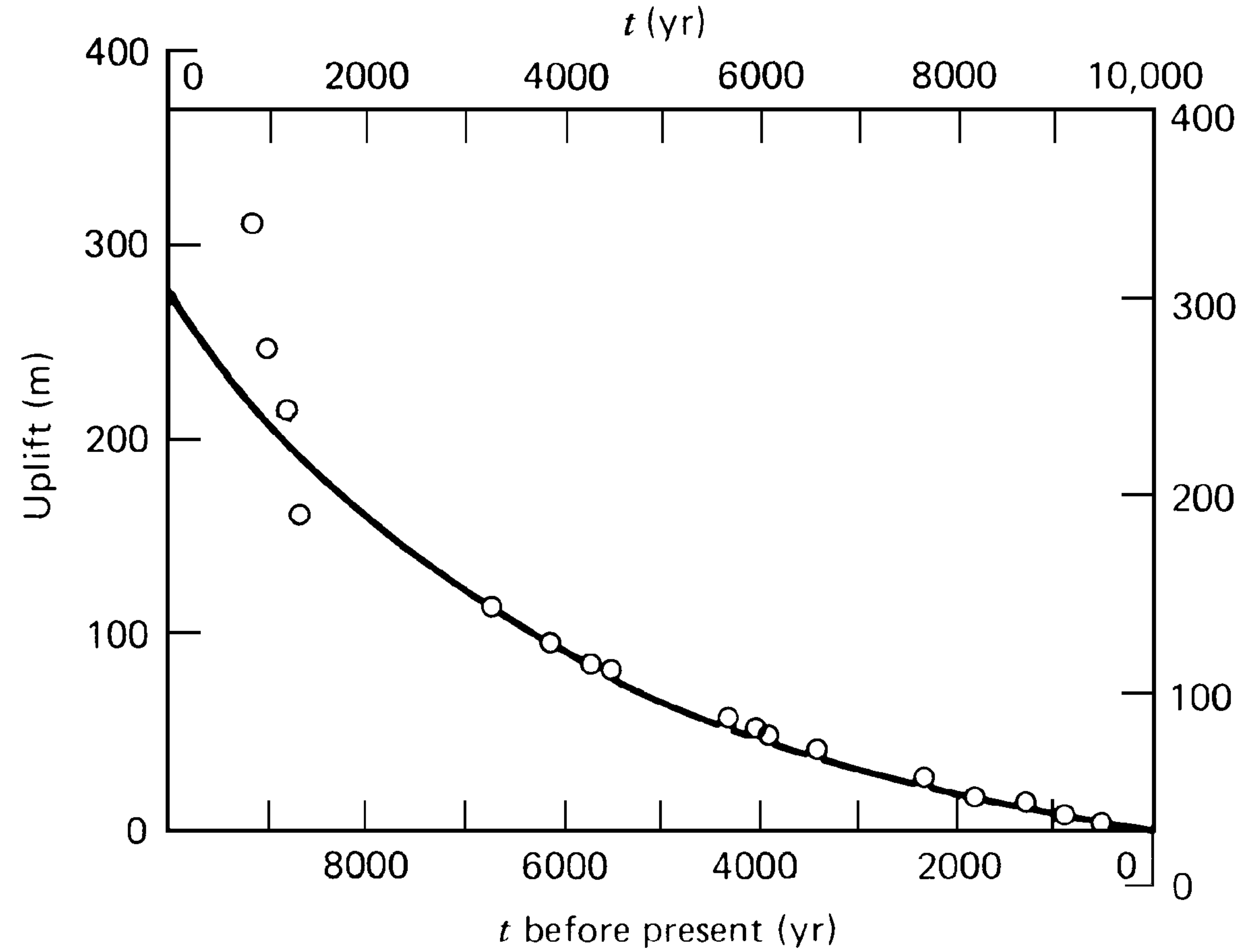
Praias soerguidas

Östergransholm, Eastern Gotland, Sweden

(Turcotte & Schubert, 2002)

Praias soerguidas

Östergransholm, Eastern Gotland, Sweden

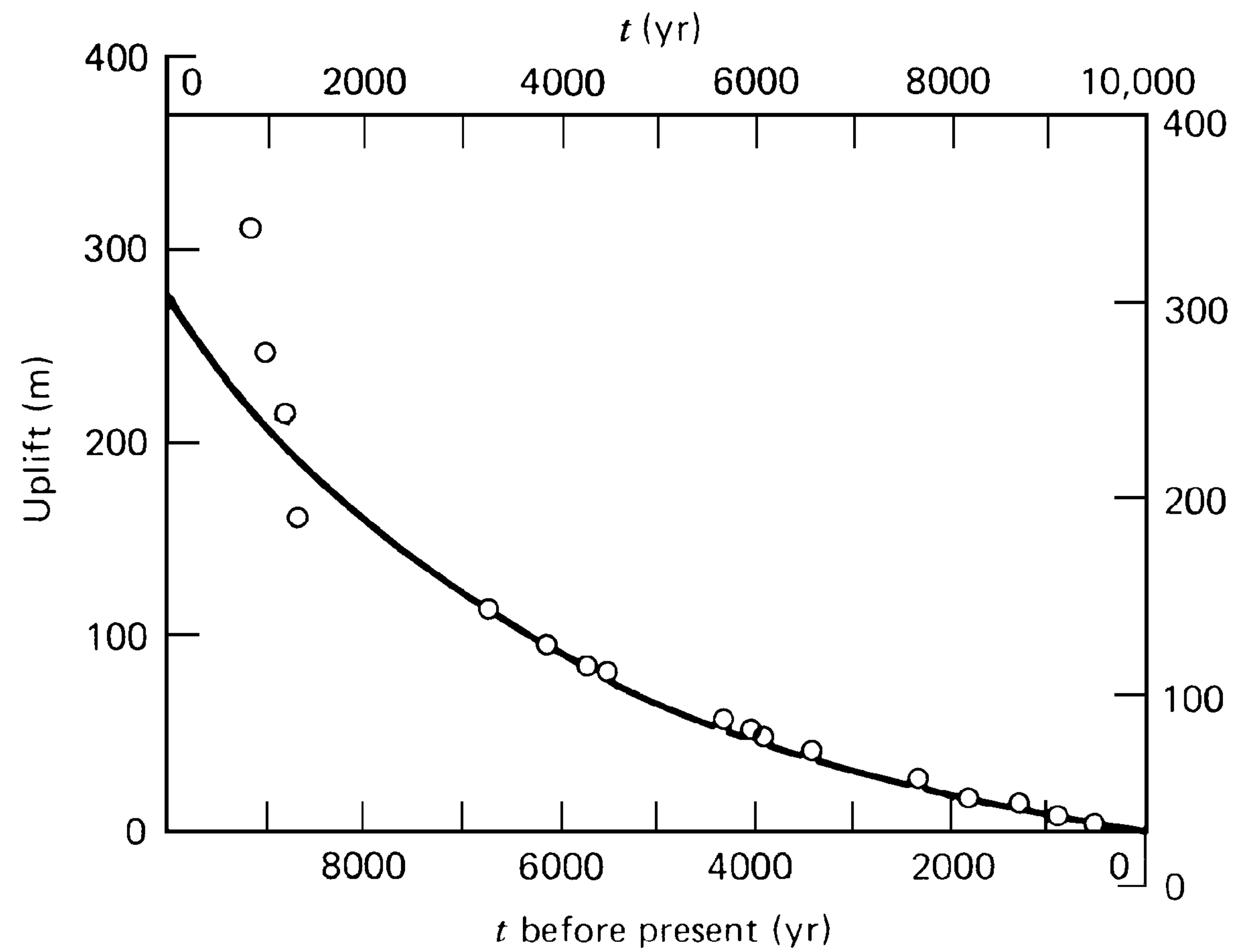


(Turcotte & Schubert, 2002)

Praias soerguidas

Östergransholm, Eastern Gotland, Sweden

(Turcotte & Schubert, 2002)

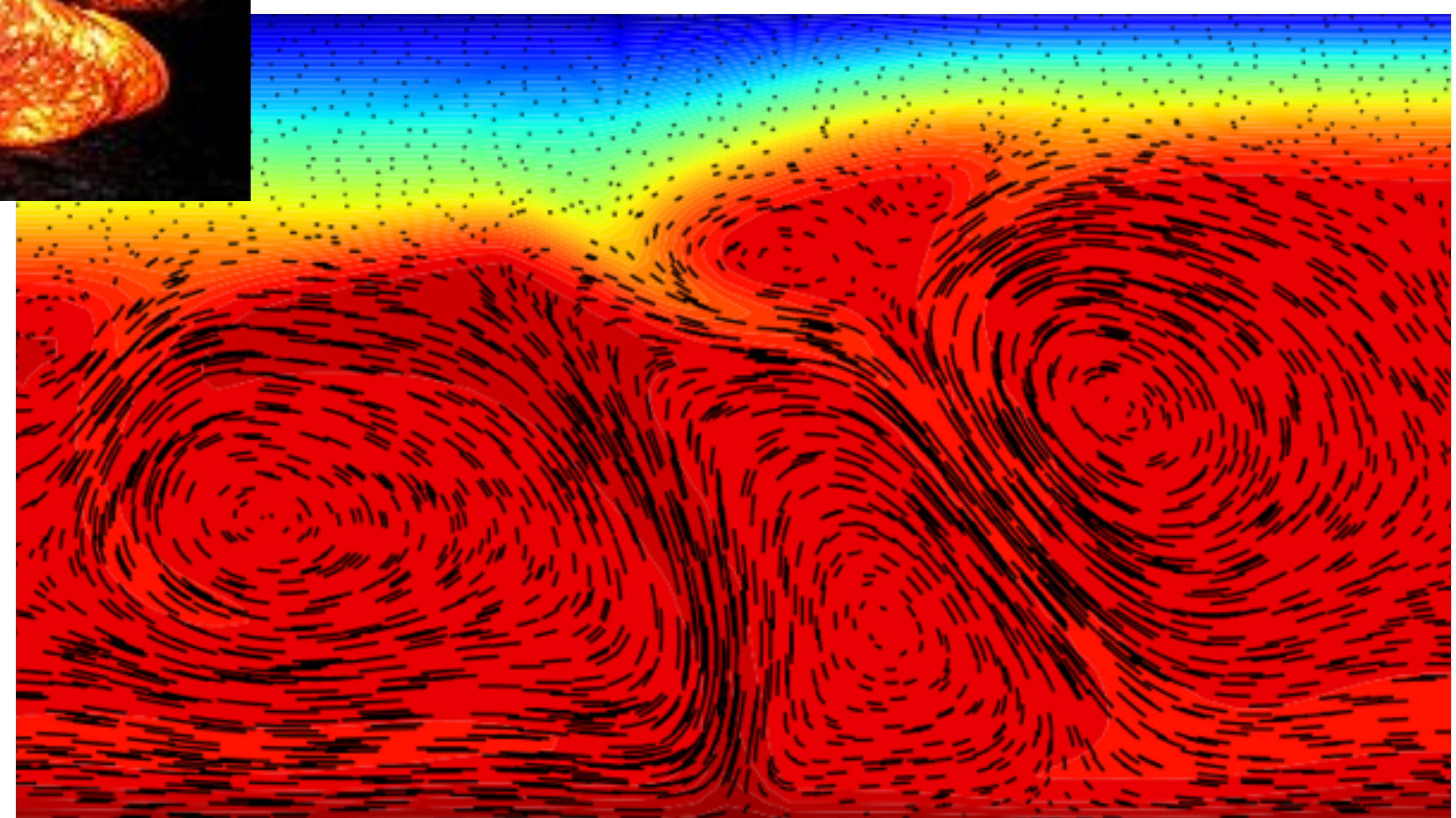


O ajuste pós-glacial ocorre em alguns milhares de anos

Diferença de viscosidade

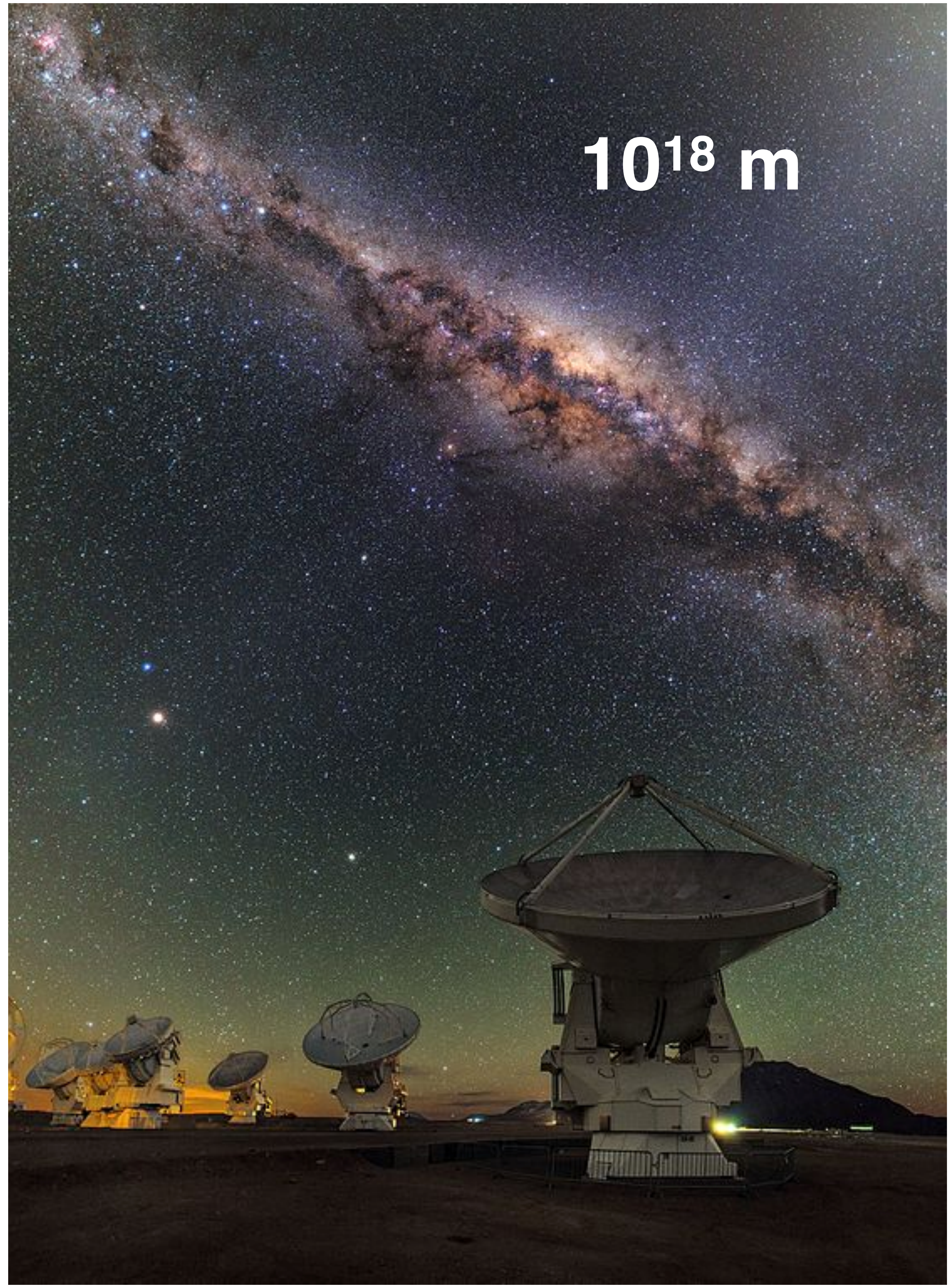
10^{2} Pa·s

10^{21} Pa·s



10^{-1} m

10^{-1} m



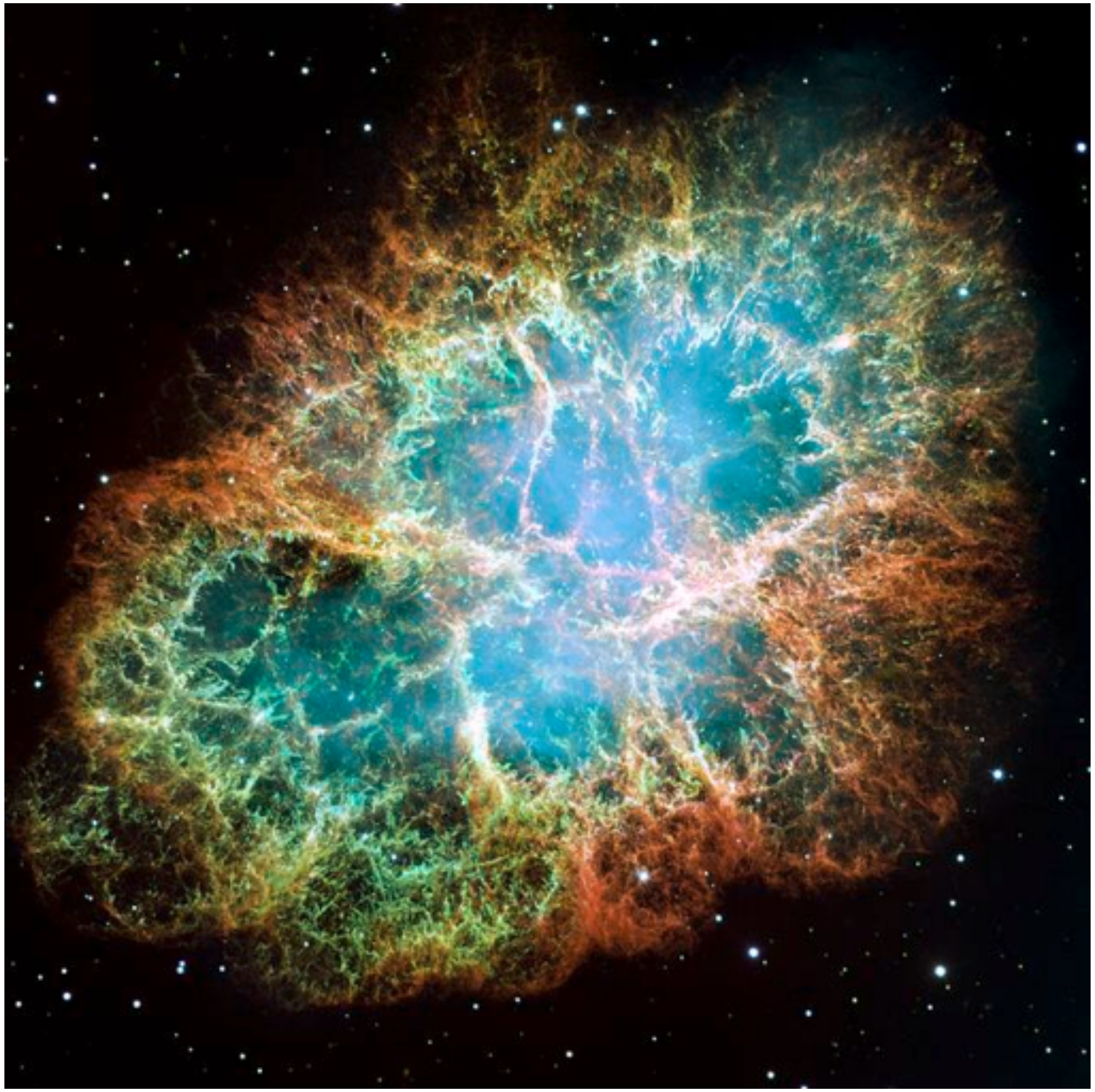
Mas será que essa viscosidade tão alta é suficiente para manter a tectônica de placas?

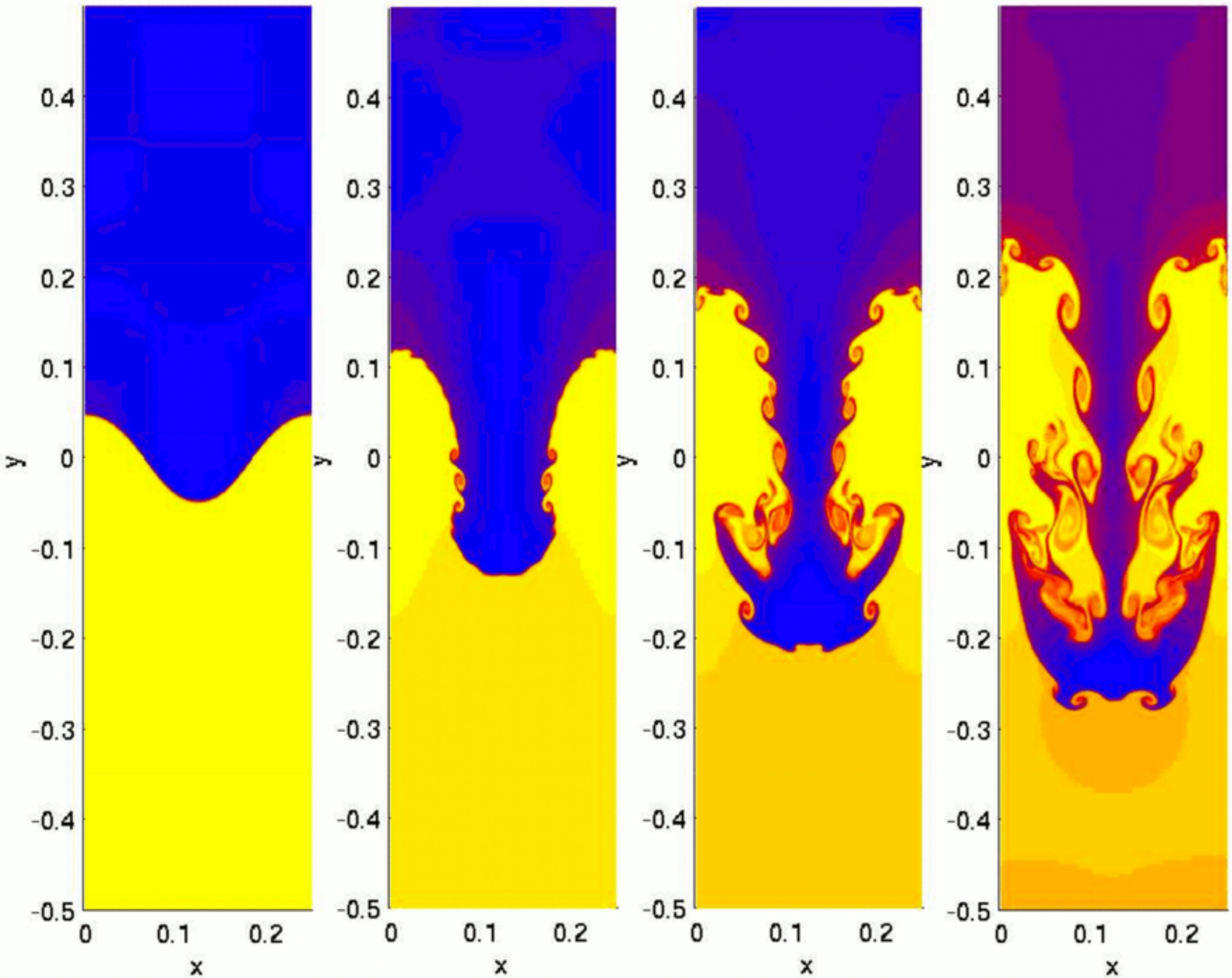
Instabilidade de Rayleigh-Taylor

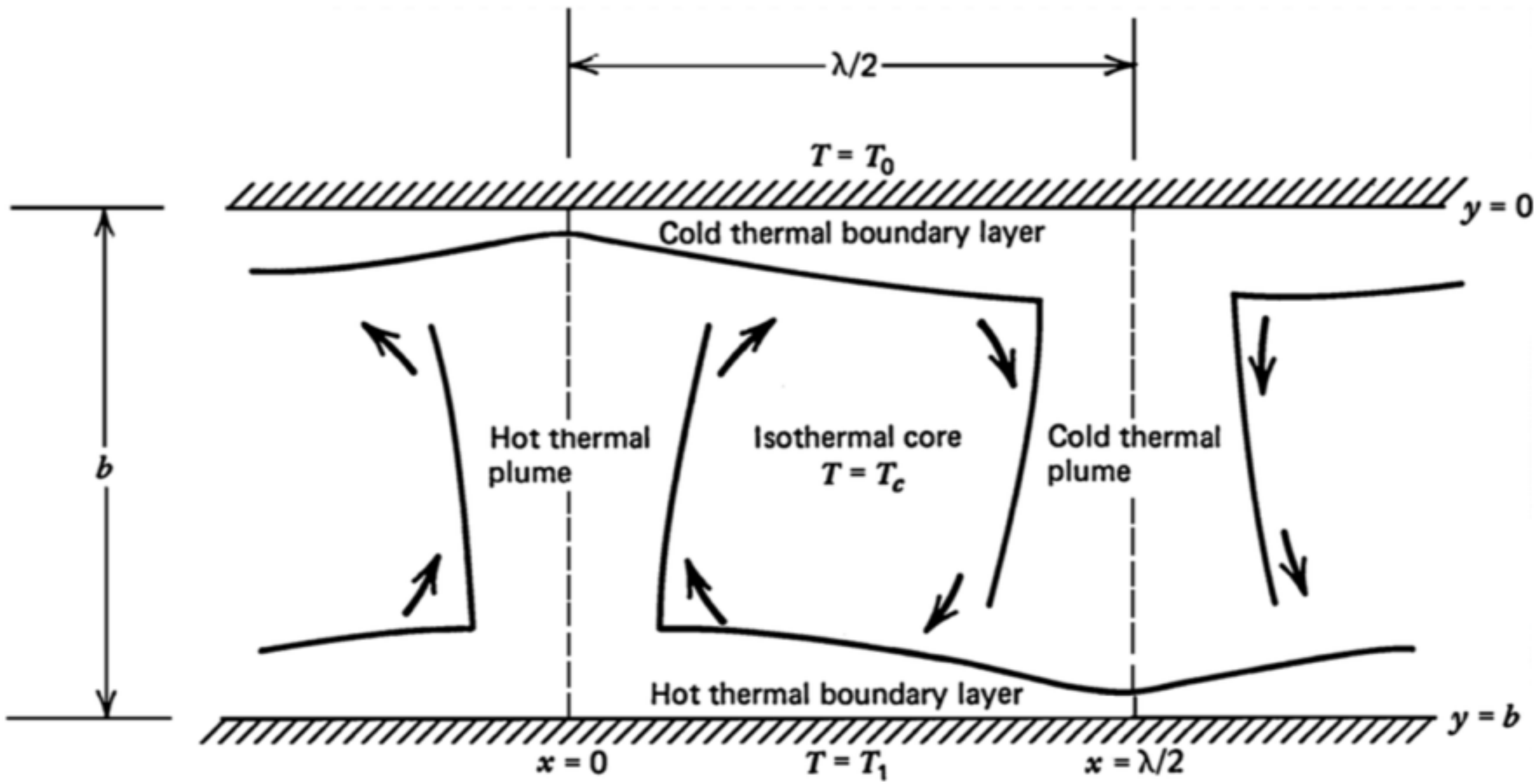
Lord Rayleigh (1842 - 1919)
Published about 450 papers in many fields in physics such as wave propagation, acoustics, optics, natural convection

Geoffrey Ingram Taylor (1886 - 1975)
Published over 250 papers in mechanics of fluids and solids with applications to meteorology, oceanography, aeronautics, metal physics, mechanical and chemical engineering.

Instabilidade de Rayleigh-Taylor

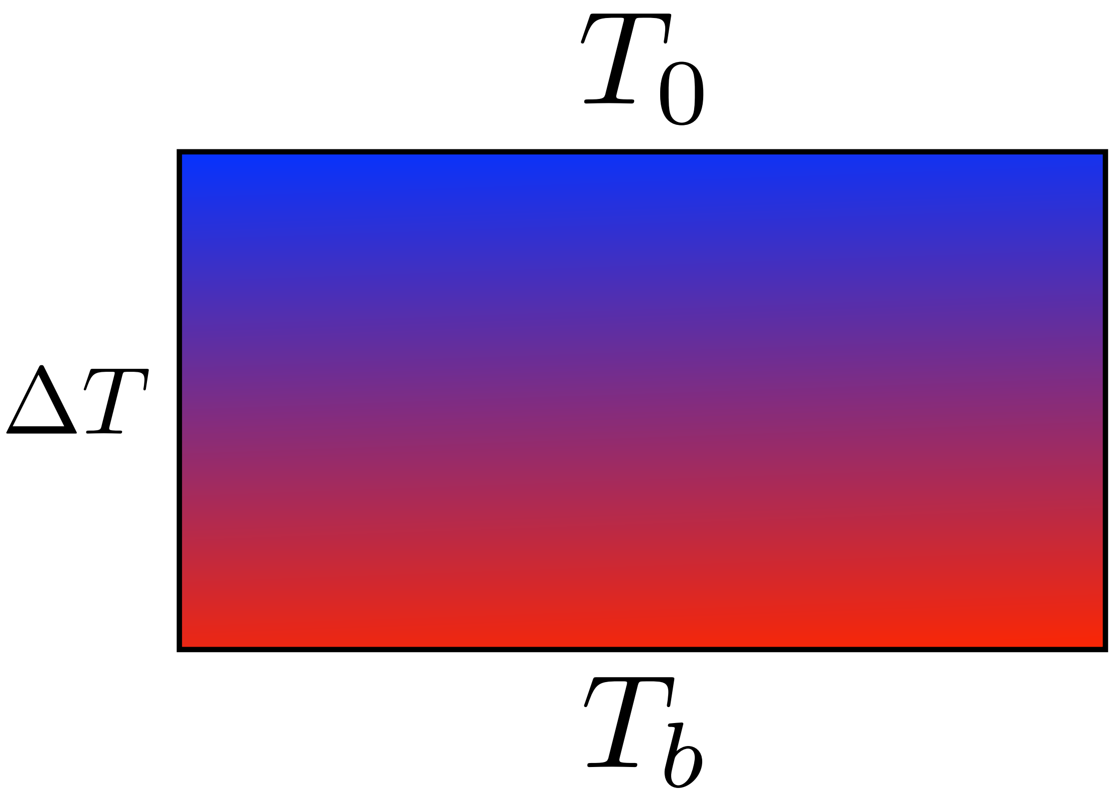


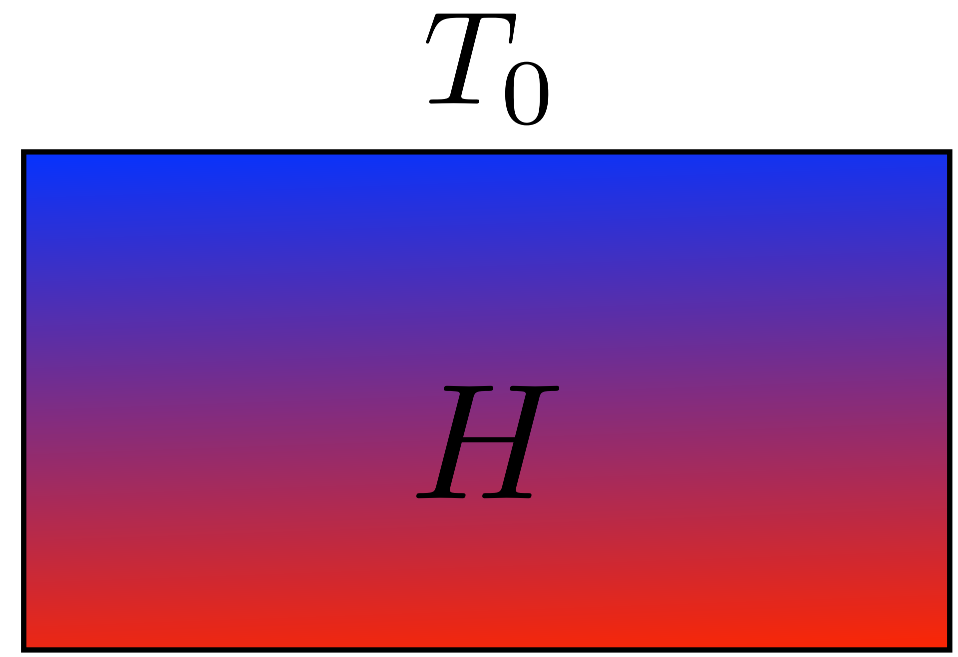

y
x
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
0
0.1
0.2



λ/2
T = T0
y = 0
Cold thermal boundary layer
Hot thermal plume
Isothermal core
T = Tc
Cold thermal plume
b
Hot thermal boundary layer
y = b
x = 0
T = T1
x = λ/2

Número de Rayleigh





$$Ra = \frac{\rho_0 g \alpha \Delta T b^3}{\mu \kappa}$$

$$Ra = \frac{\alpha \rho_0^2 g H b^5}{k \mu \kappa}$$

Número de Rayleigh

$$Ra = \frac{\rho_0 g \alpha \Delta T b^3}{\mu \kappa}$$

$$Ra = \frac{\alpha \rho_0^2 g H b^5}{k \mu \kappa}$$

ρ_0 : densidade

g : gravidade

α : coef. de expansão volumétrica

ΔT : contraste de temperatura (topo-base)

b : altura

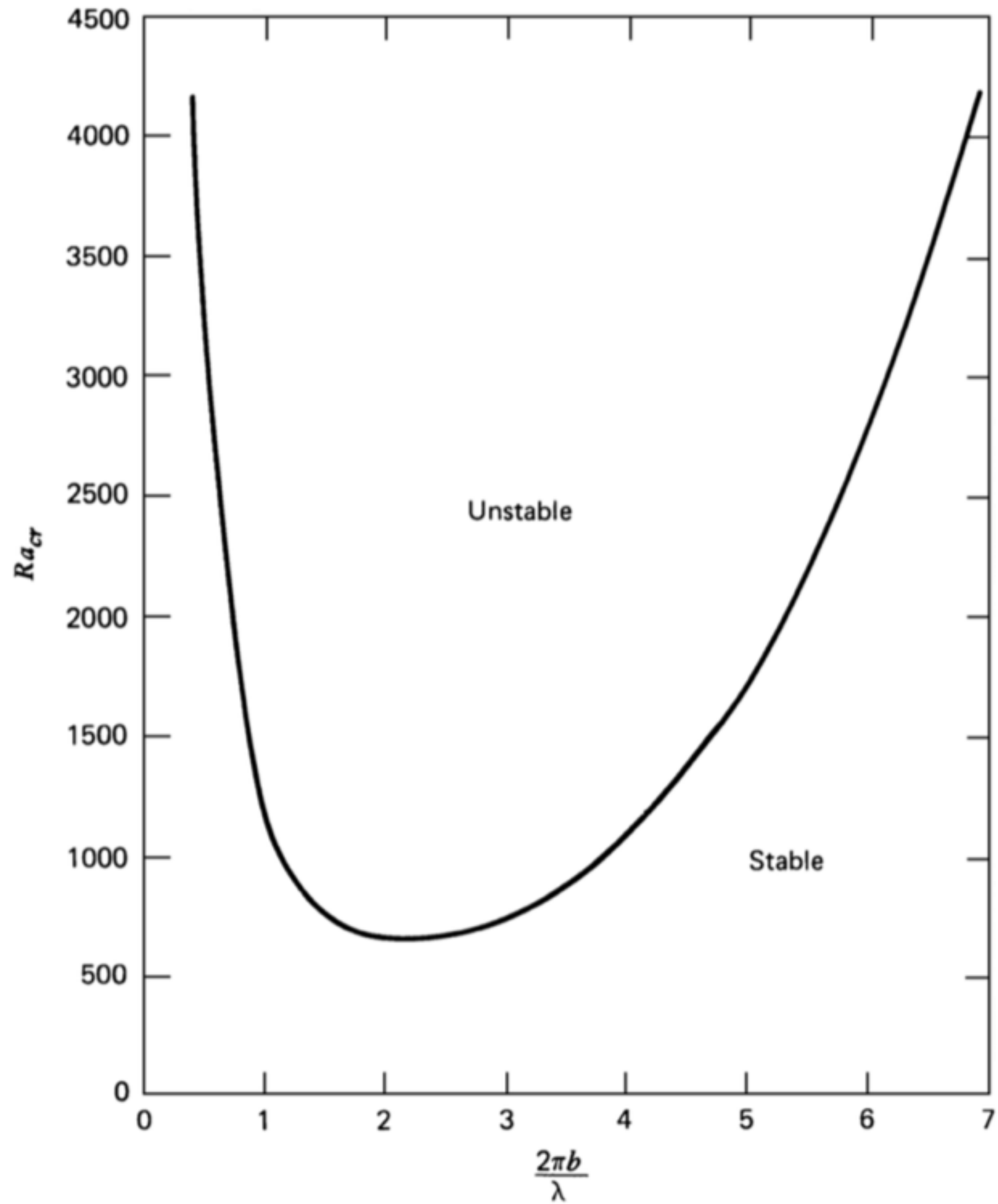
μ : viscosidade

κ : difusividade térmica

H: produção de calor interno

k : condutividade térmica

$$\mathrm{Ra} > \frac{(\pi^2 + \frac{4\pi^2 b^2}{\lambda^2})^3}{\frac{4\pi^2 b^2}{\lambda^2}}.$$



$$\mathrm{Ra} > \frac{\left(\pi^2 + \frac{4\pi^2 b^2}{\lambda^2}\right)^3}{\frac{4\pi^2 b^2}{\lambda^2}}.$$

$$Ra = \frac{\rho_0 g \alpha \Delta T b^3}{\mu \kappa}$$

ρ_0: 4000 kg/m^3

g : 10 m/s^2

α : 3x10^{-5} K^{-1}

ΔT: 2000 K

$$Ra = \frac{\alpha \rho_0^2 g H b^5}{k \mu \kappa}$$

b : 700 km

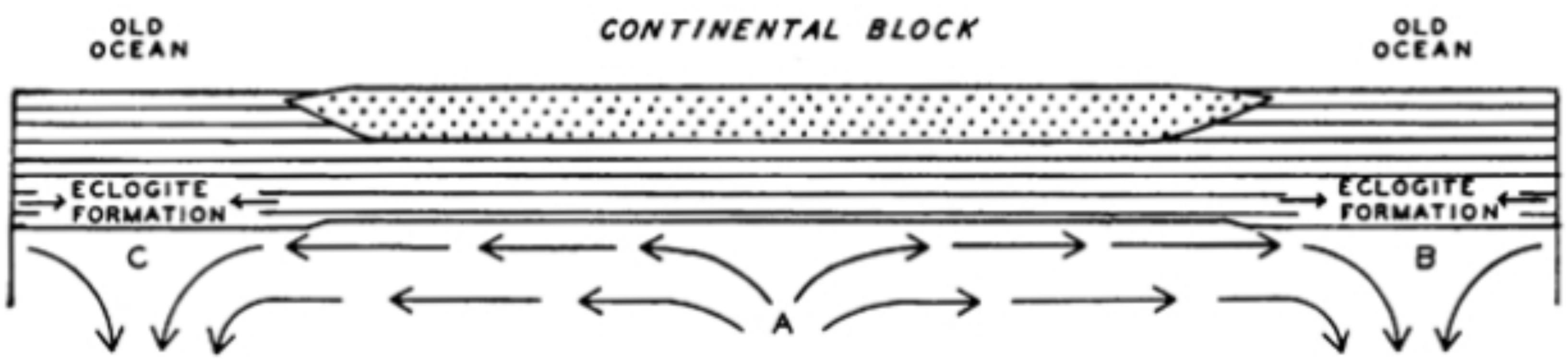
μ : 10^{21} Pa.s

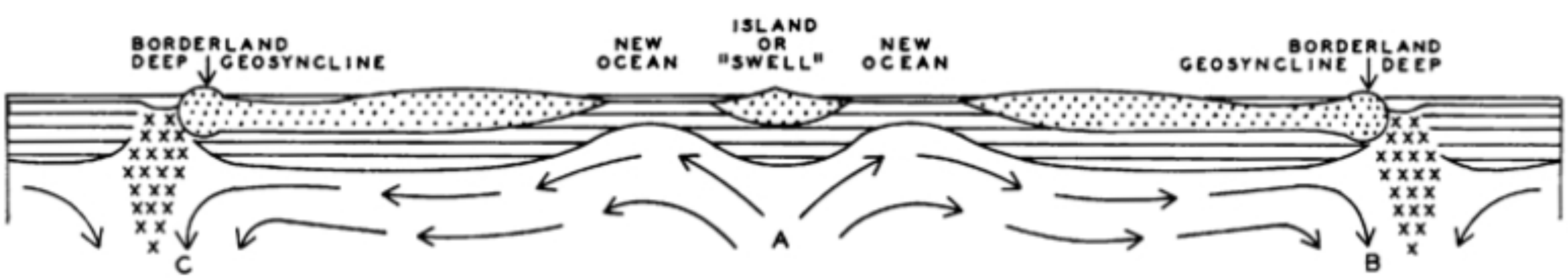
κ : 10^{-6} m^2/s

H : 9x10^{-12} W/kg

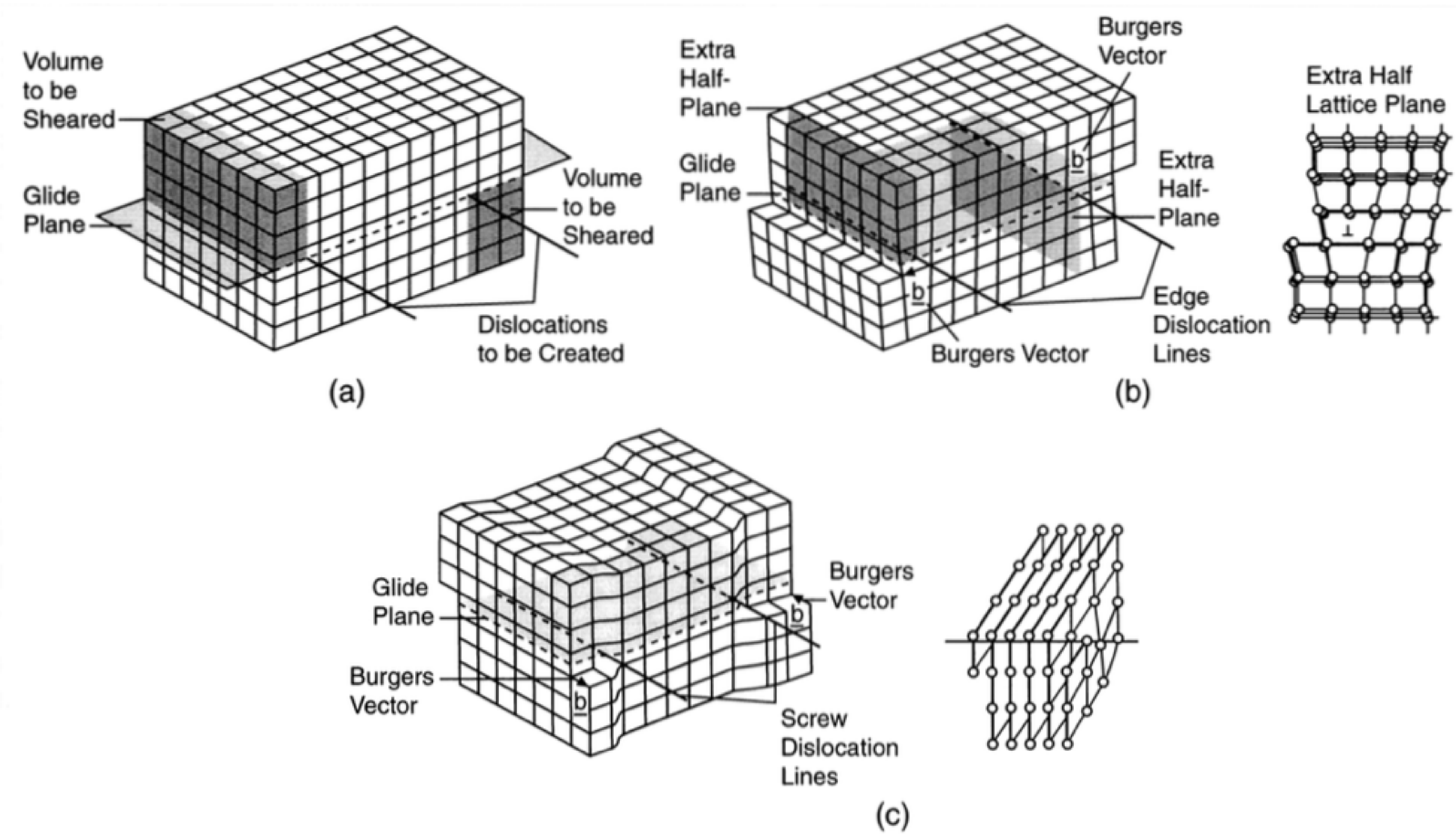
k : 4 W / m / K

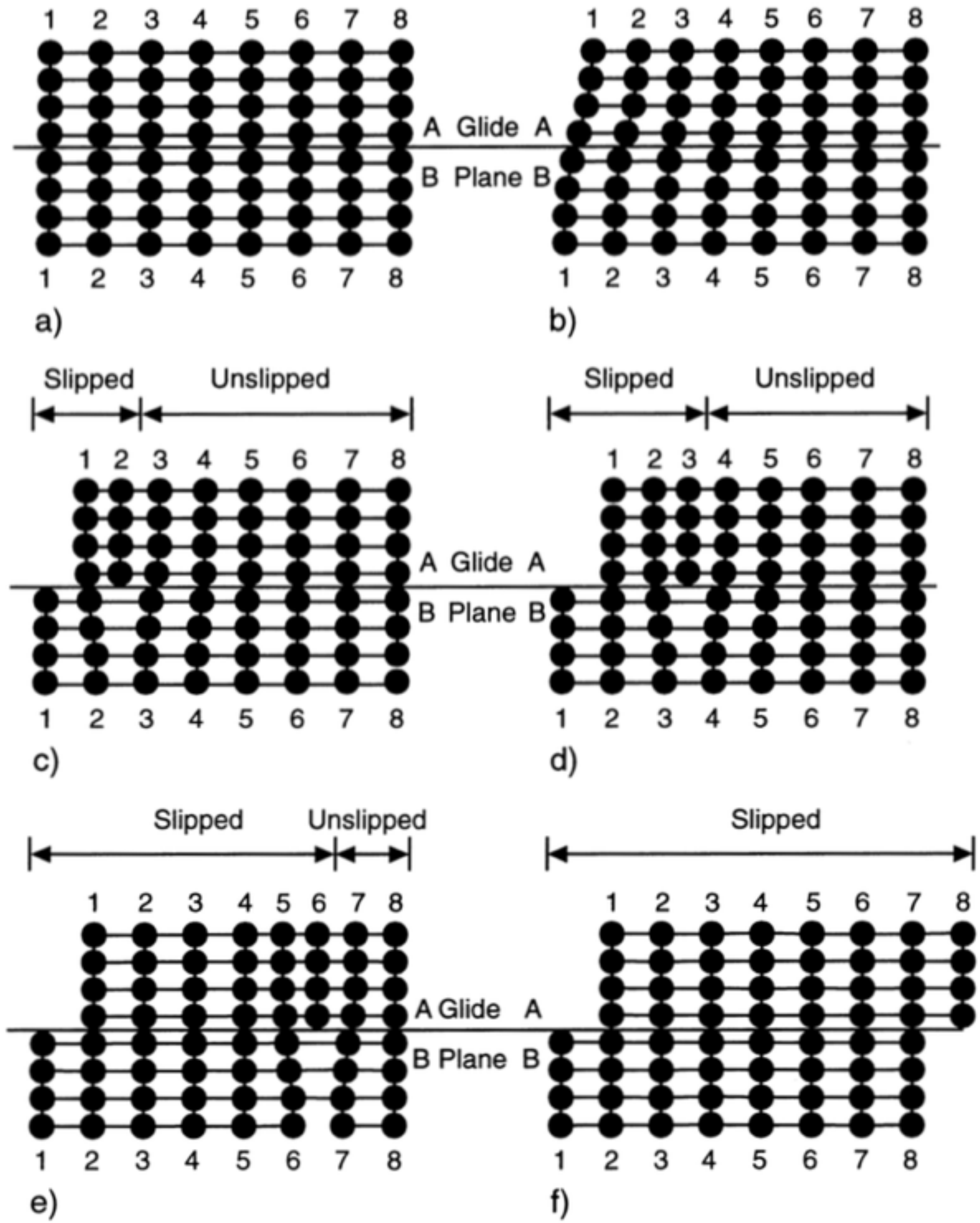
Arthur Holmes (1931)





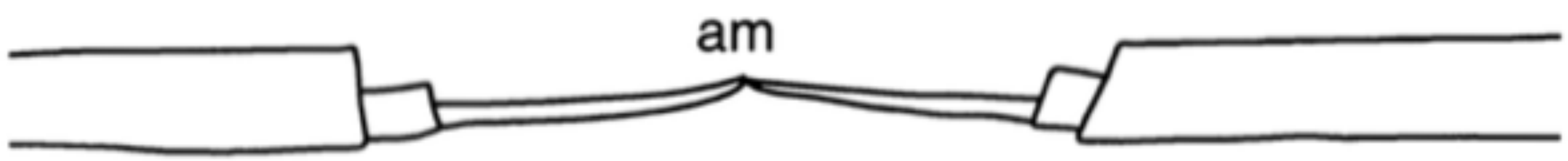
Creep (arrasto)



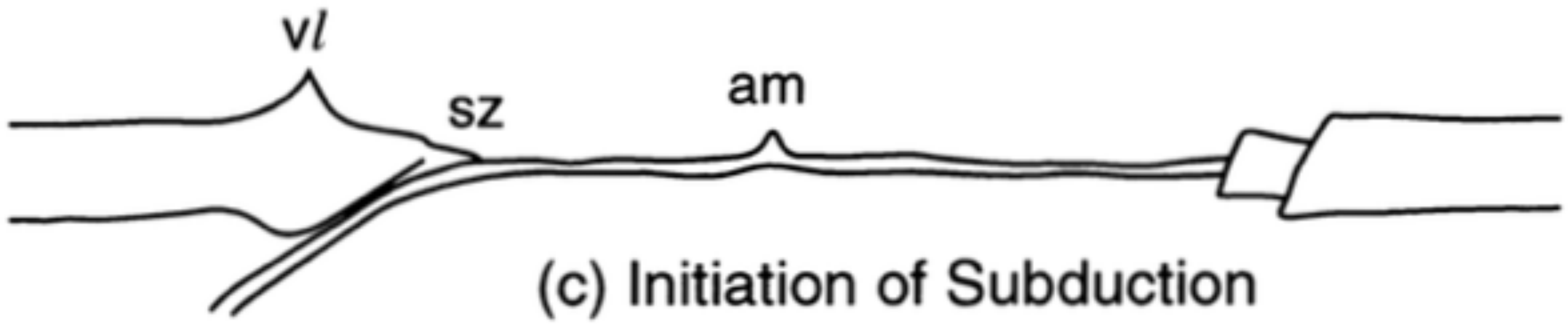


1 2 3 4 5 6 7 8
A Glide A
B Plane B
1 2 3 4 5 6 7 8
a)
b)
Slipped
Unslipped
c)
d)
e)
f)

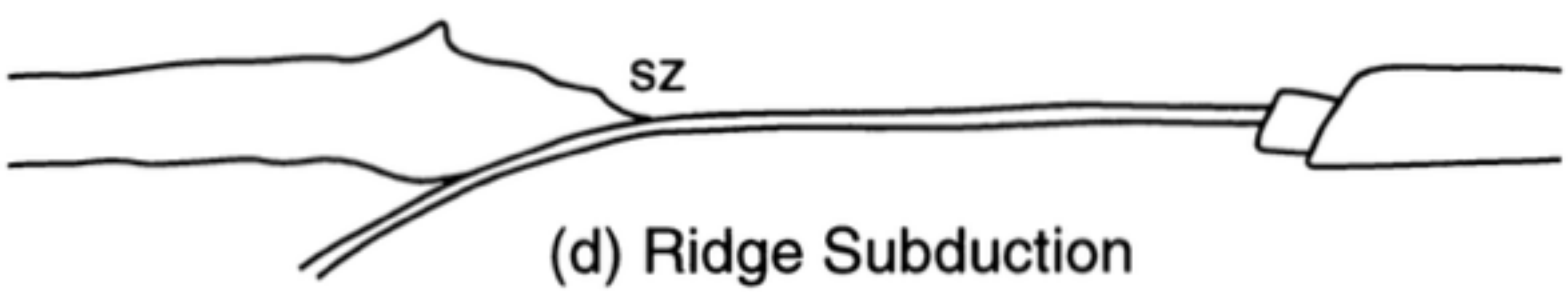
(a) Continental Rift



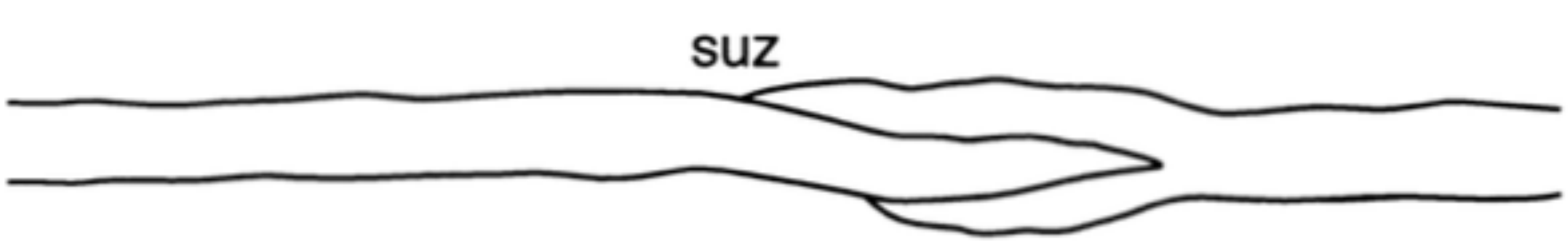
(b) Growing Ocean



(c) Initiation of Subduction

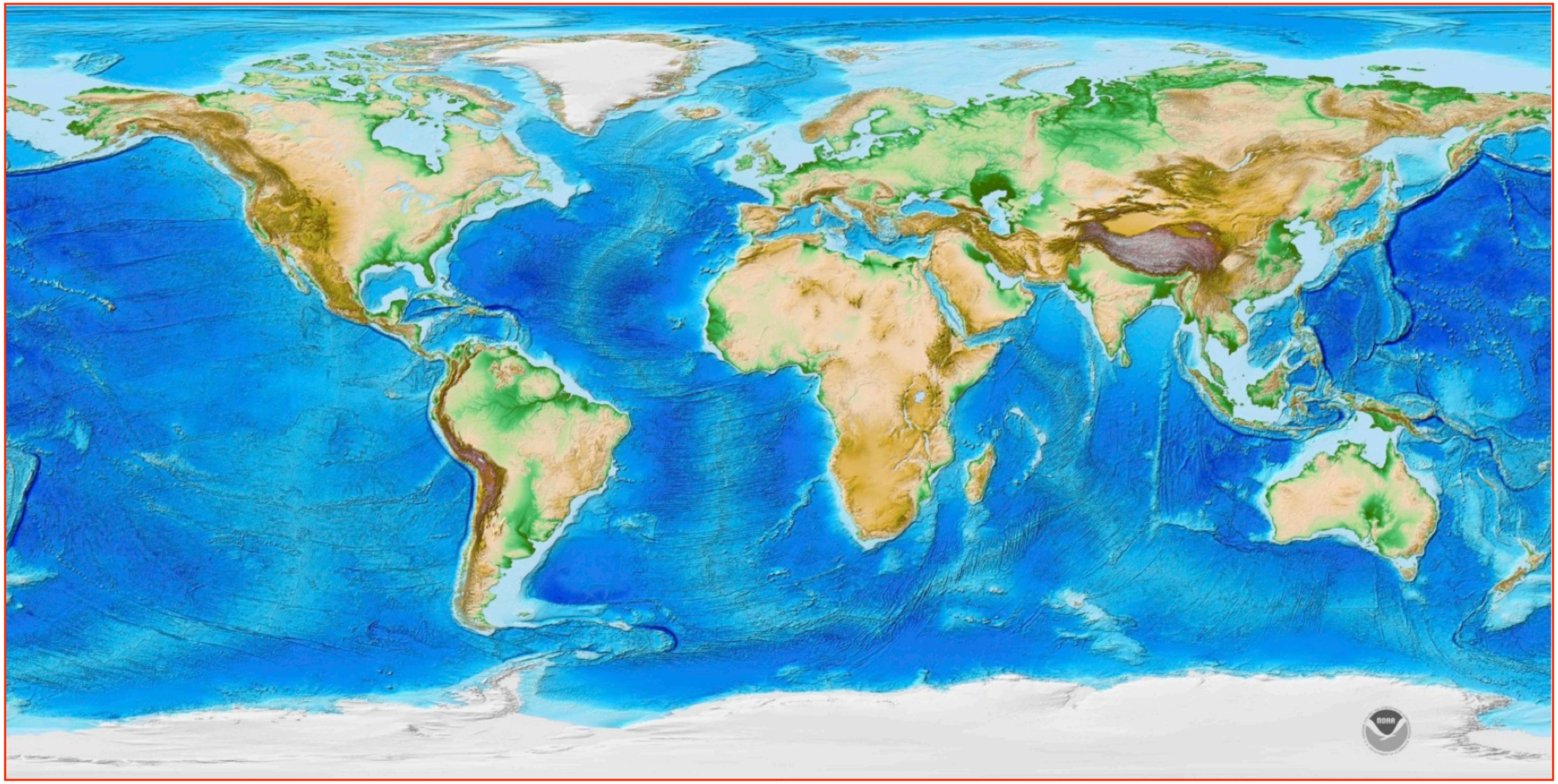


(d) Ridge Subduction

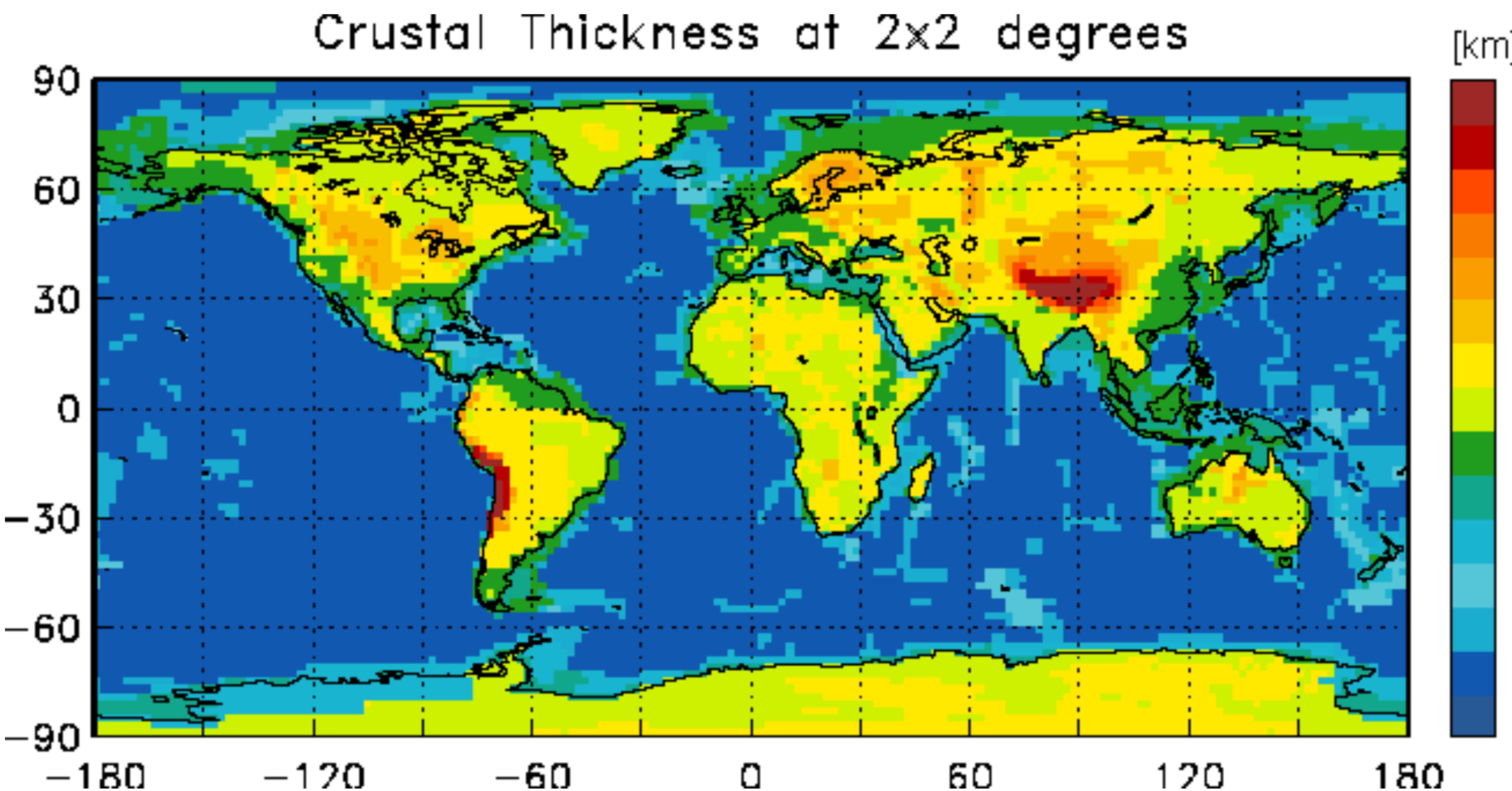


(e) Continental Collision

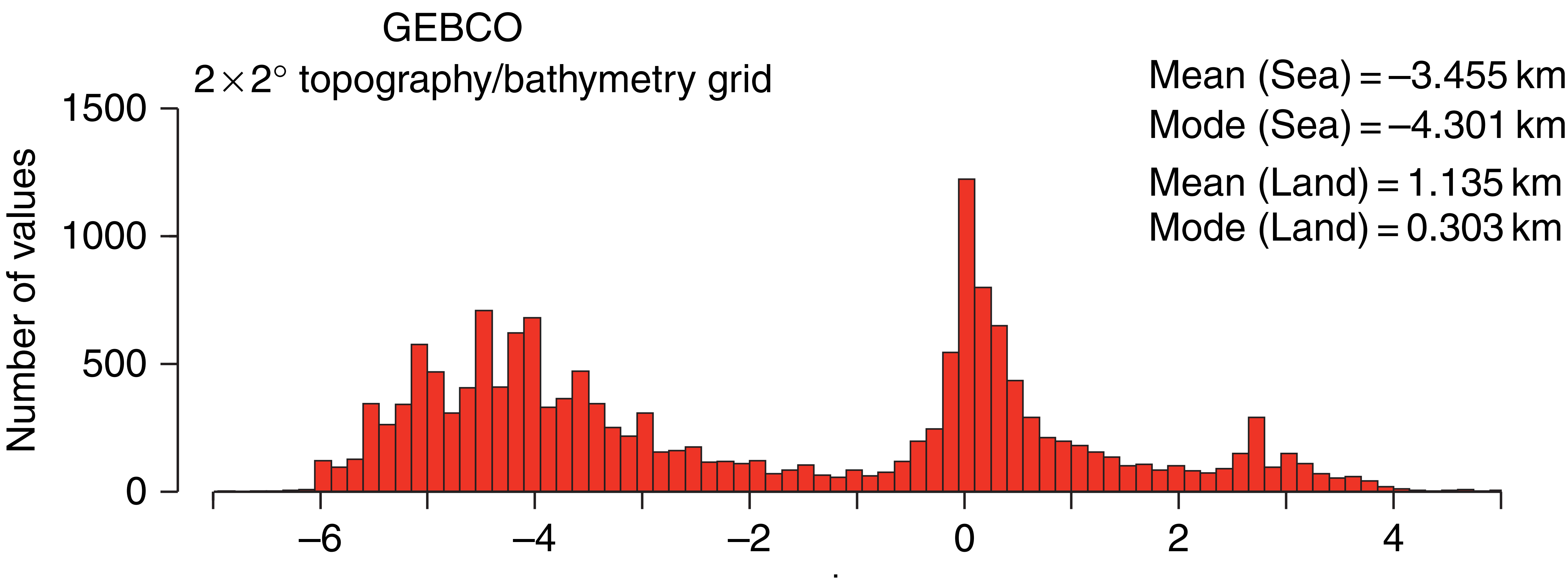
Topografia/Batimetria

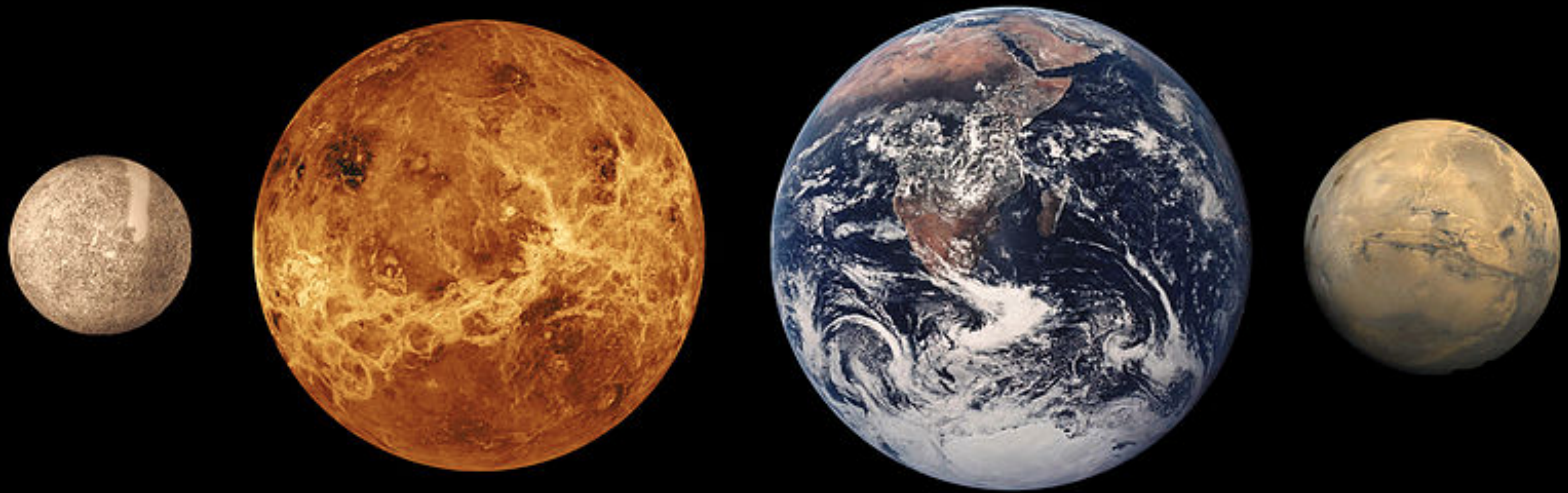


Espessura da Crosta



Batimetria/Topografia da Terra





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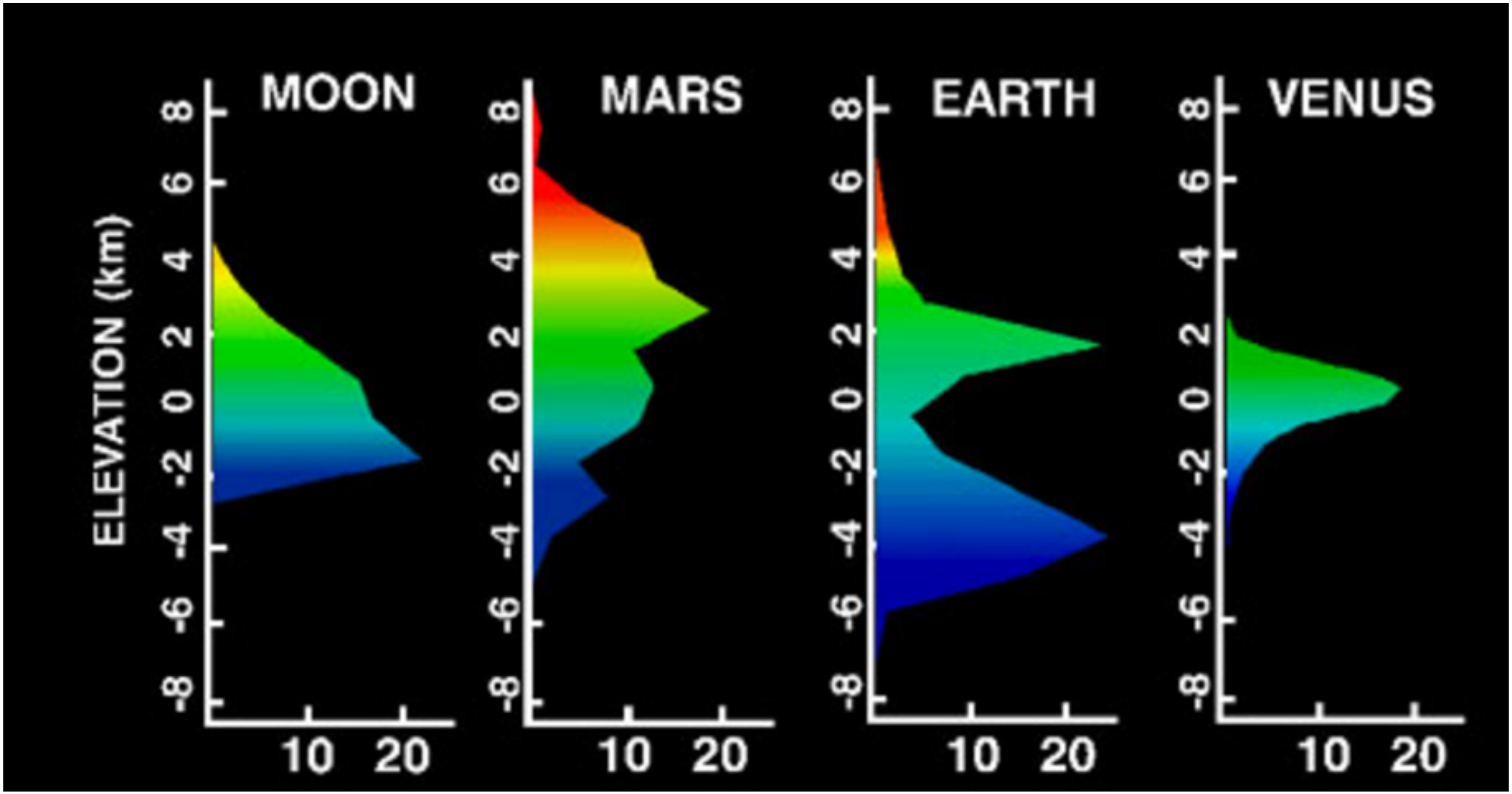
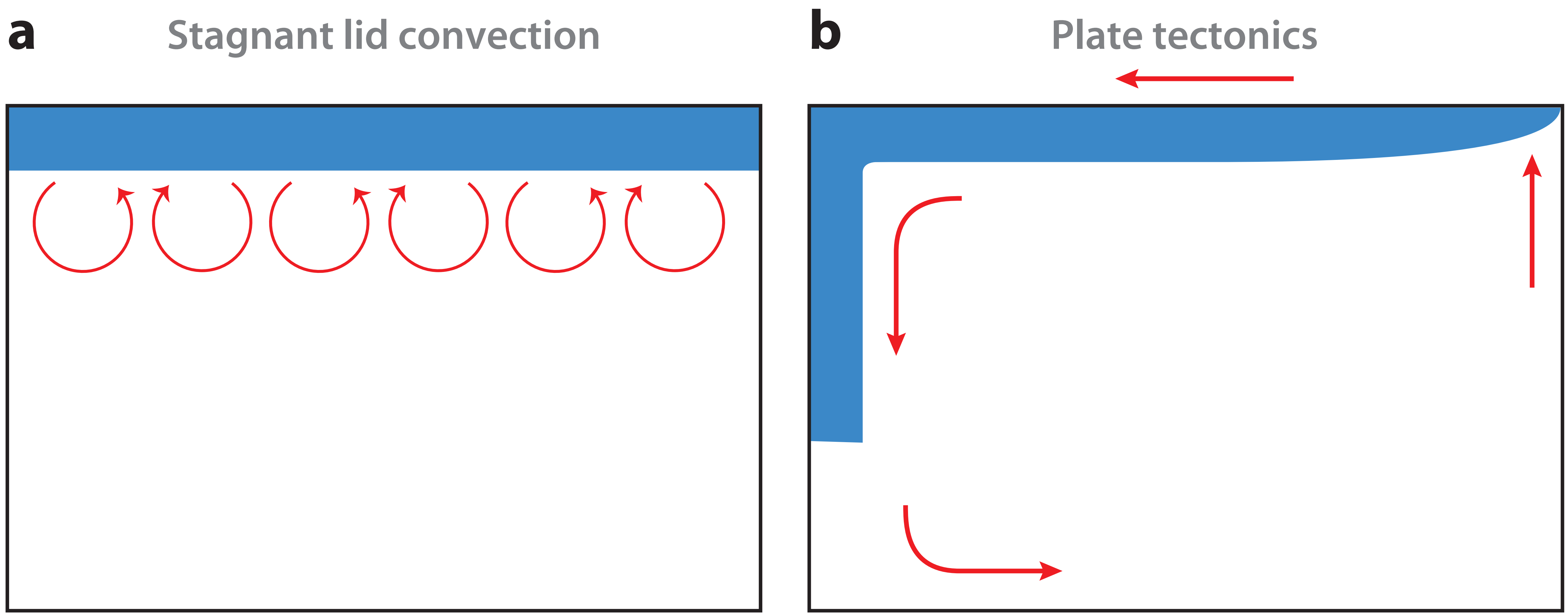
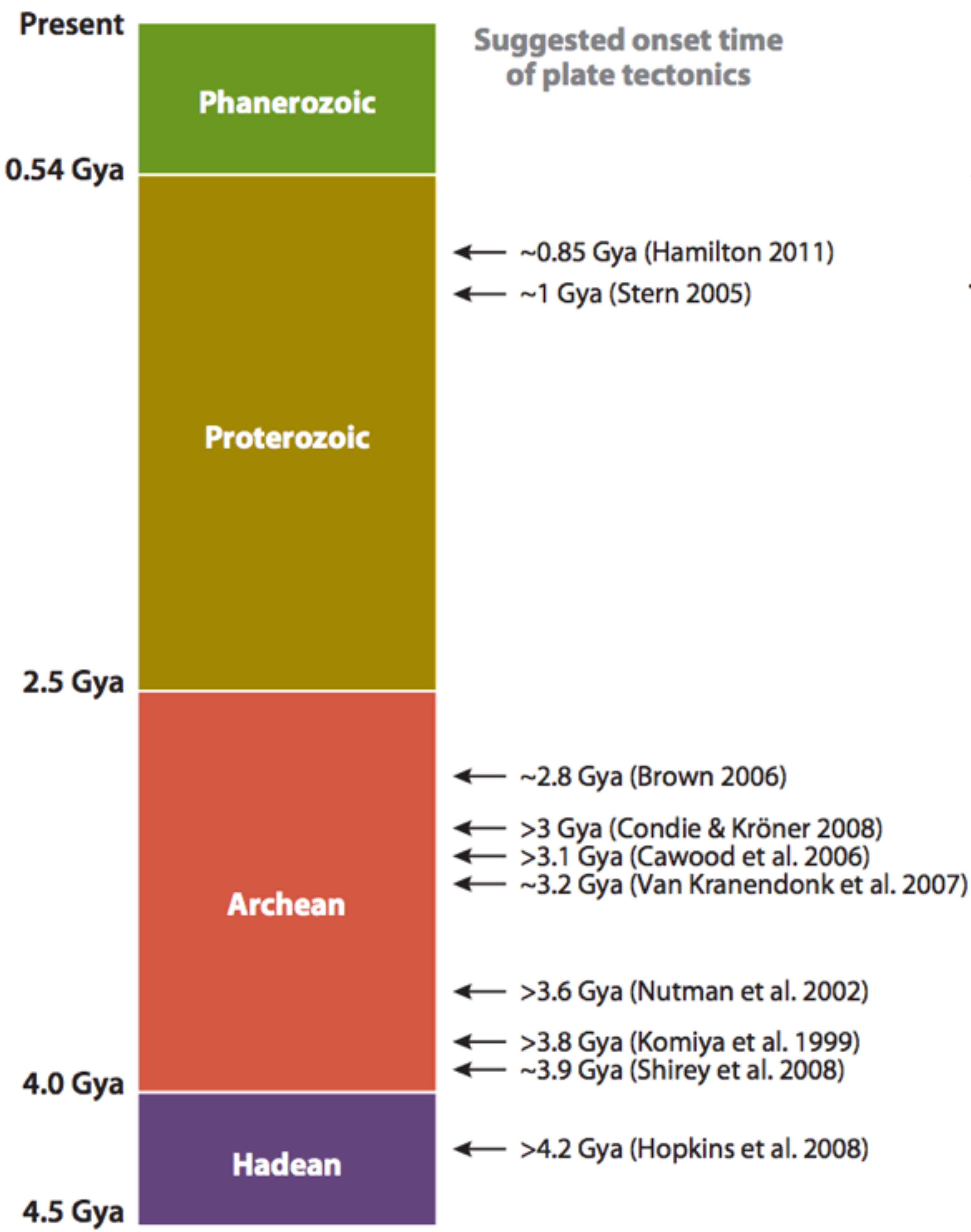


Tampa estagnada x Tectônica de placas





Initiation and Evolution of Plate Tectonics on Earth: Theories and Observations

Jun Korenaga

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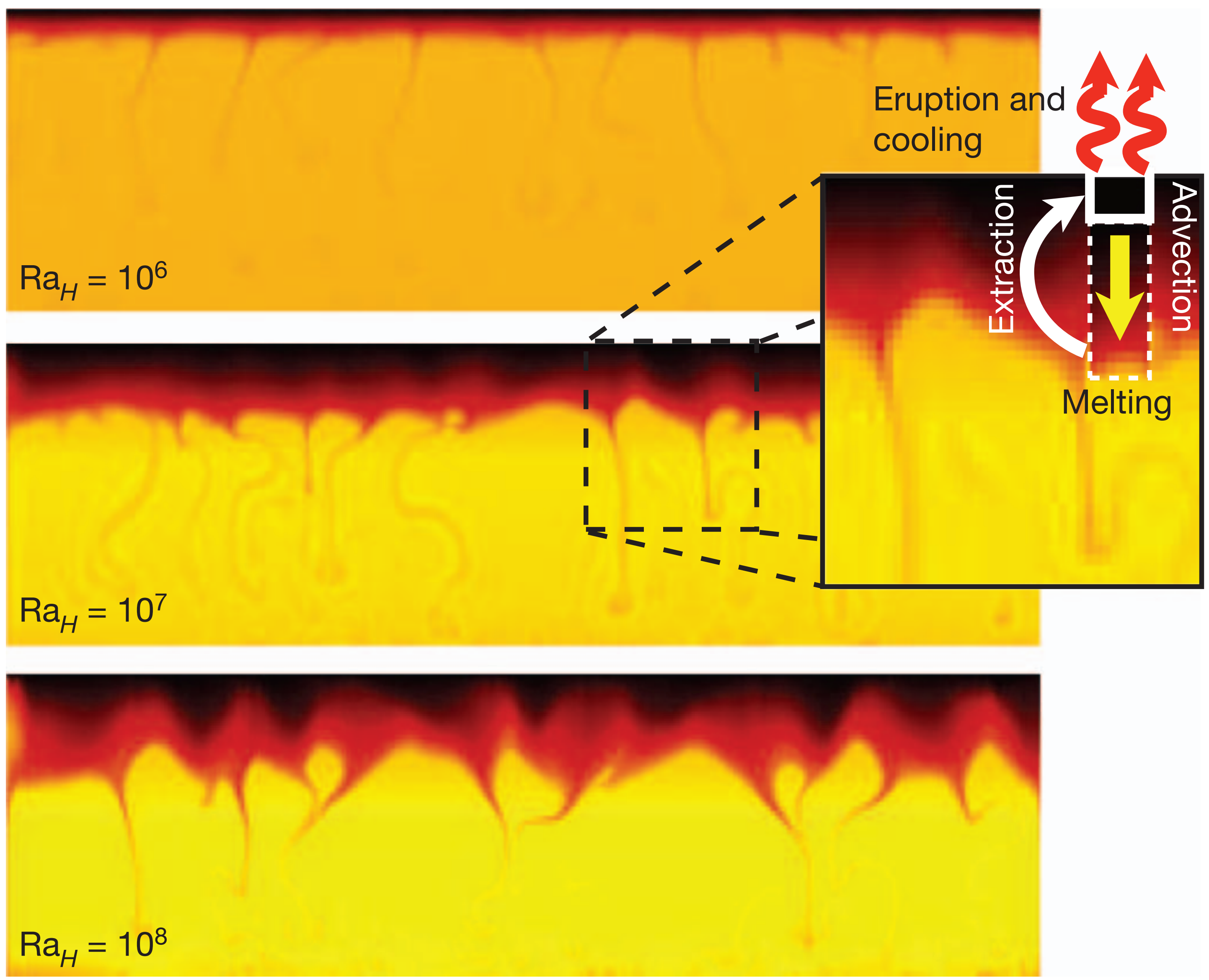
ARTICLE

doi:10.1038/nature12473

Heat-pipe Earth

William B. Moore[1,2] & A. Alexander G. Webb[3]



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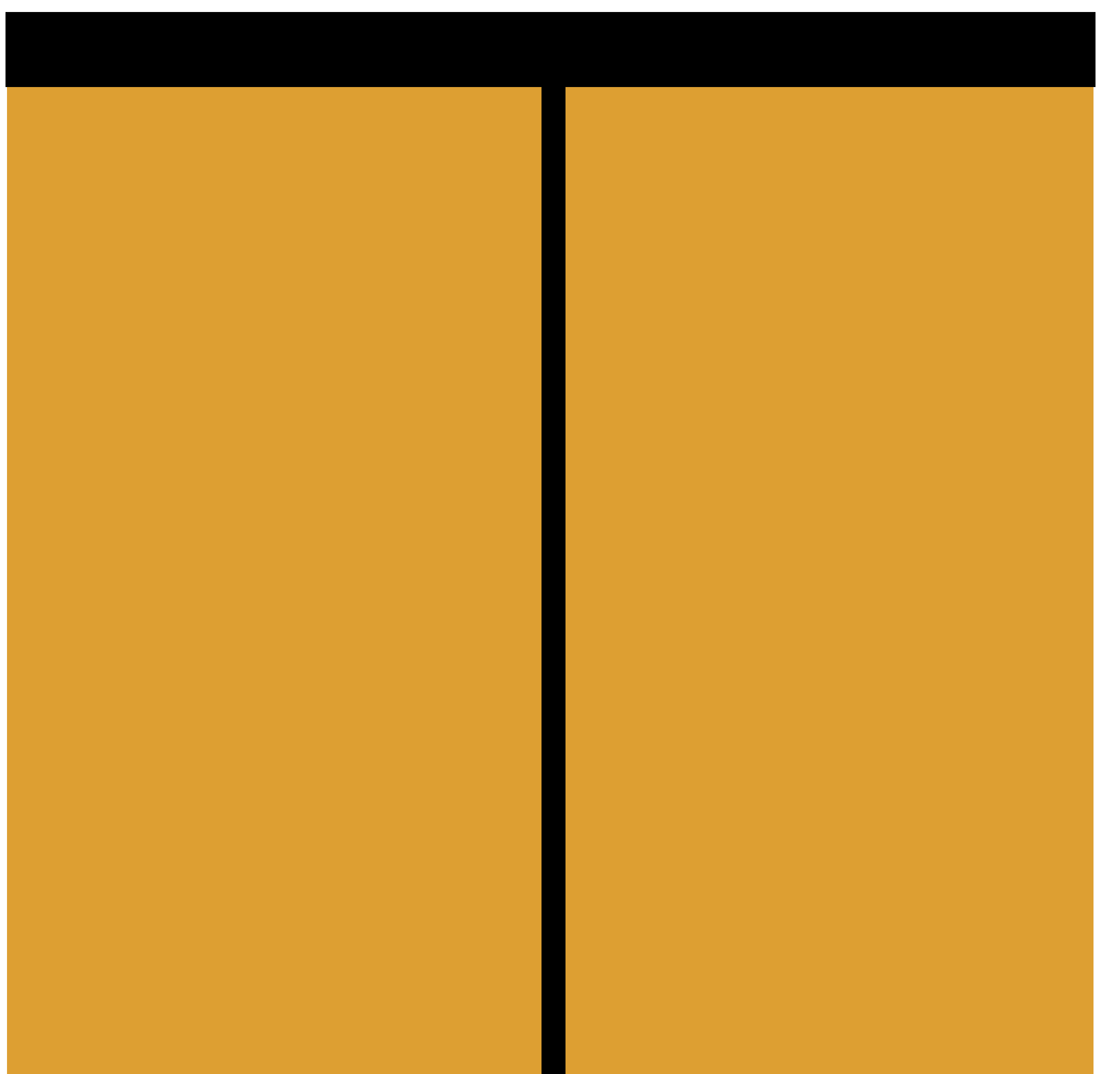

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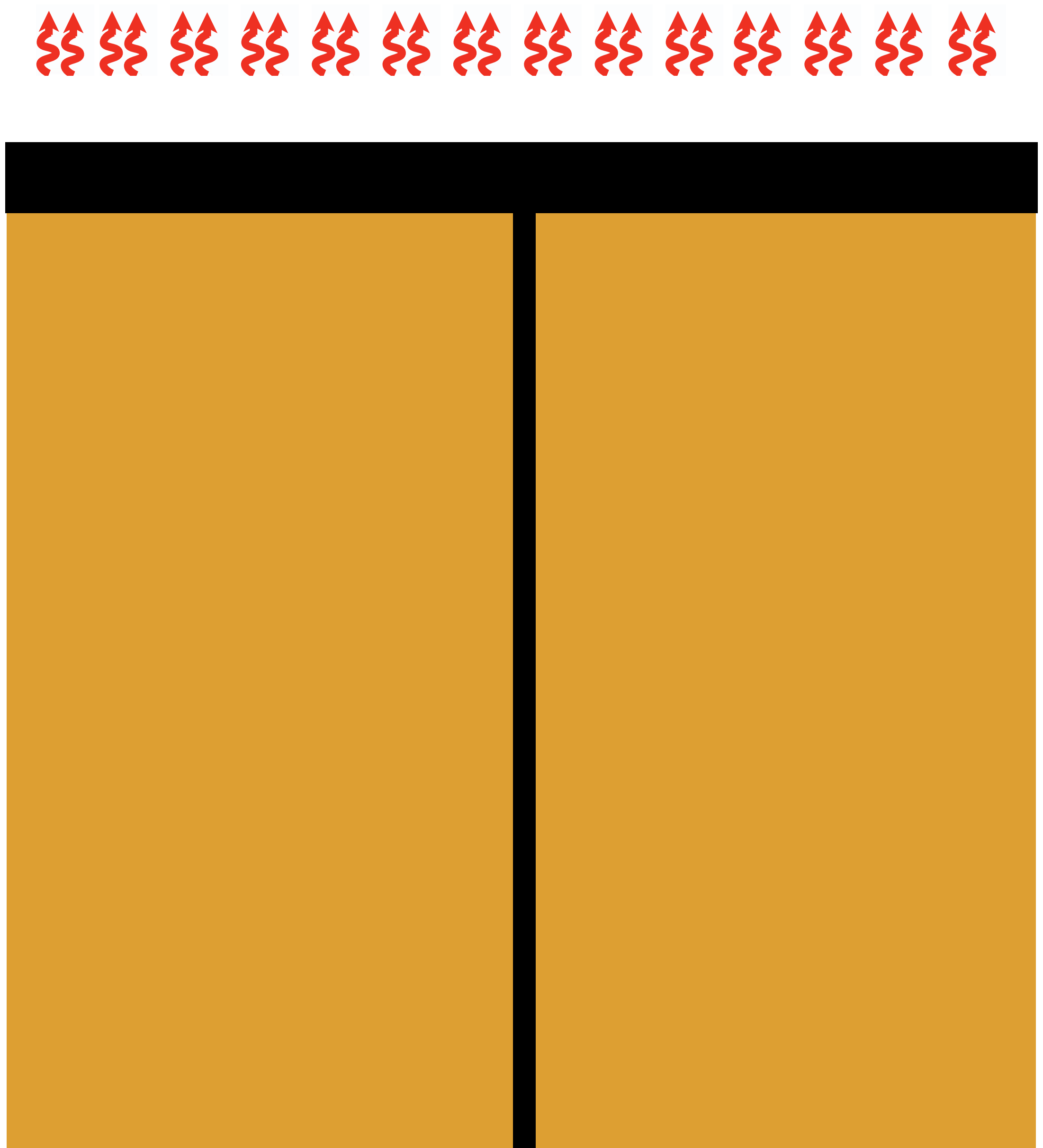

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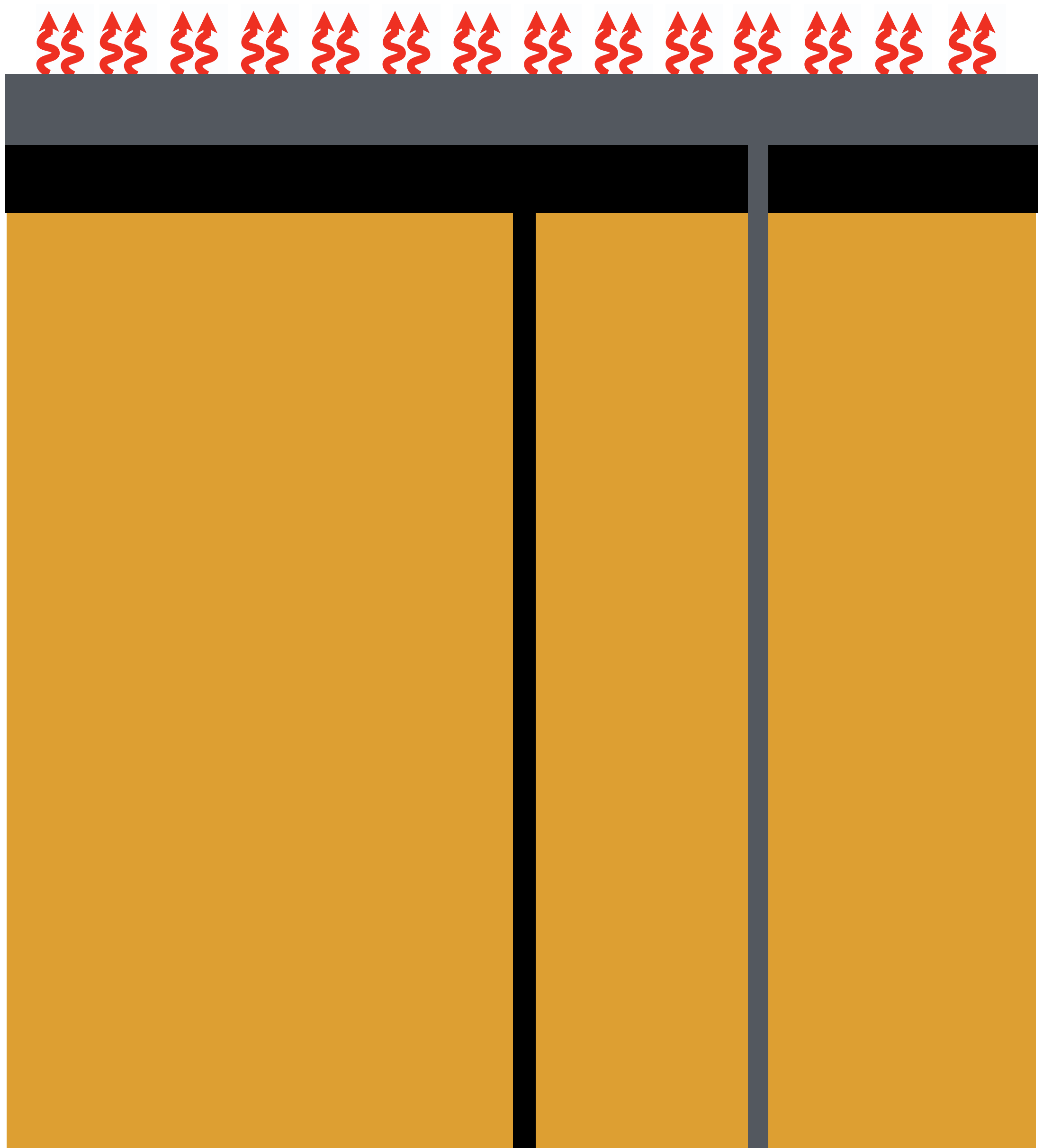

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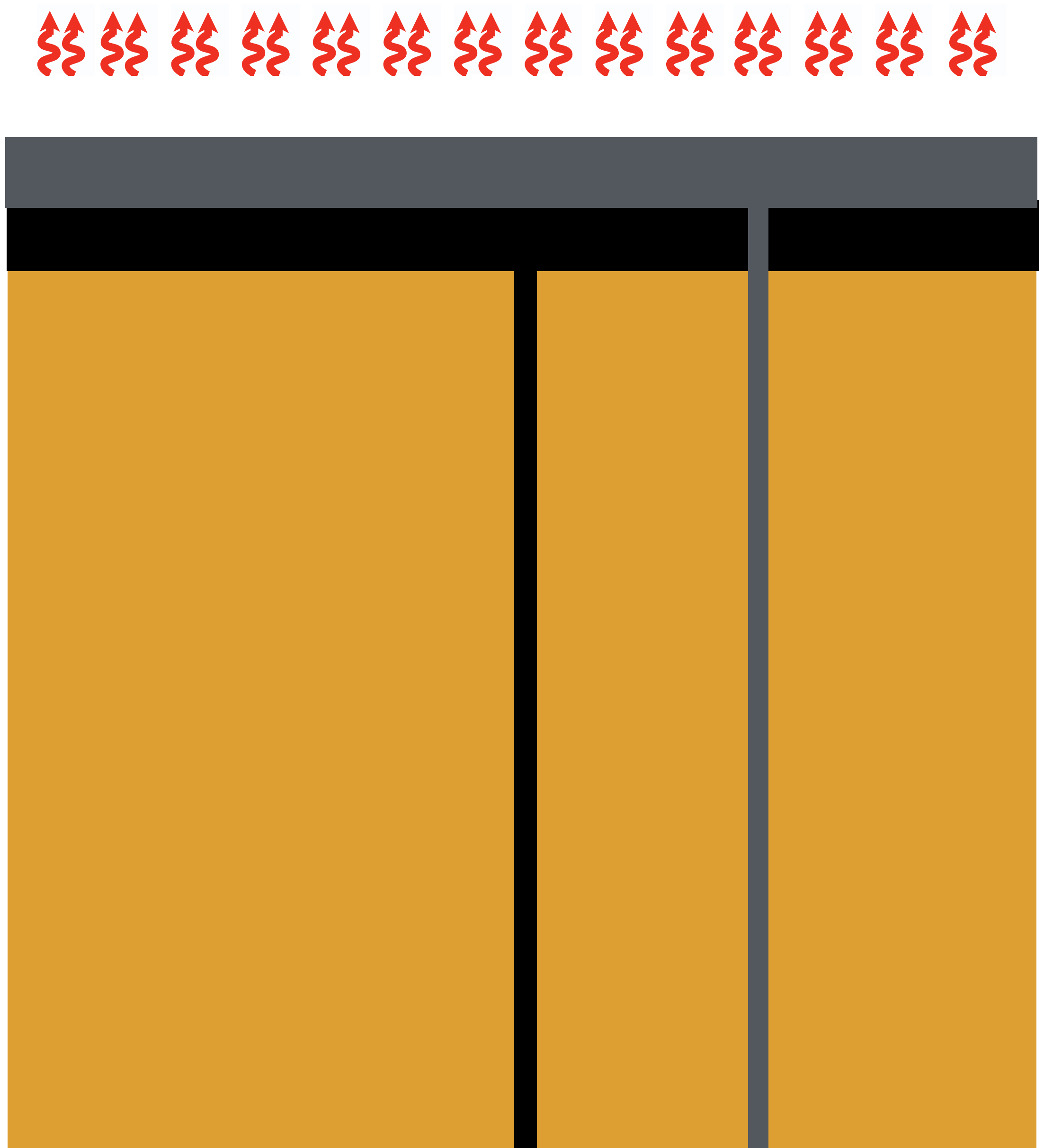

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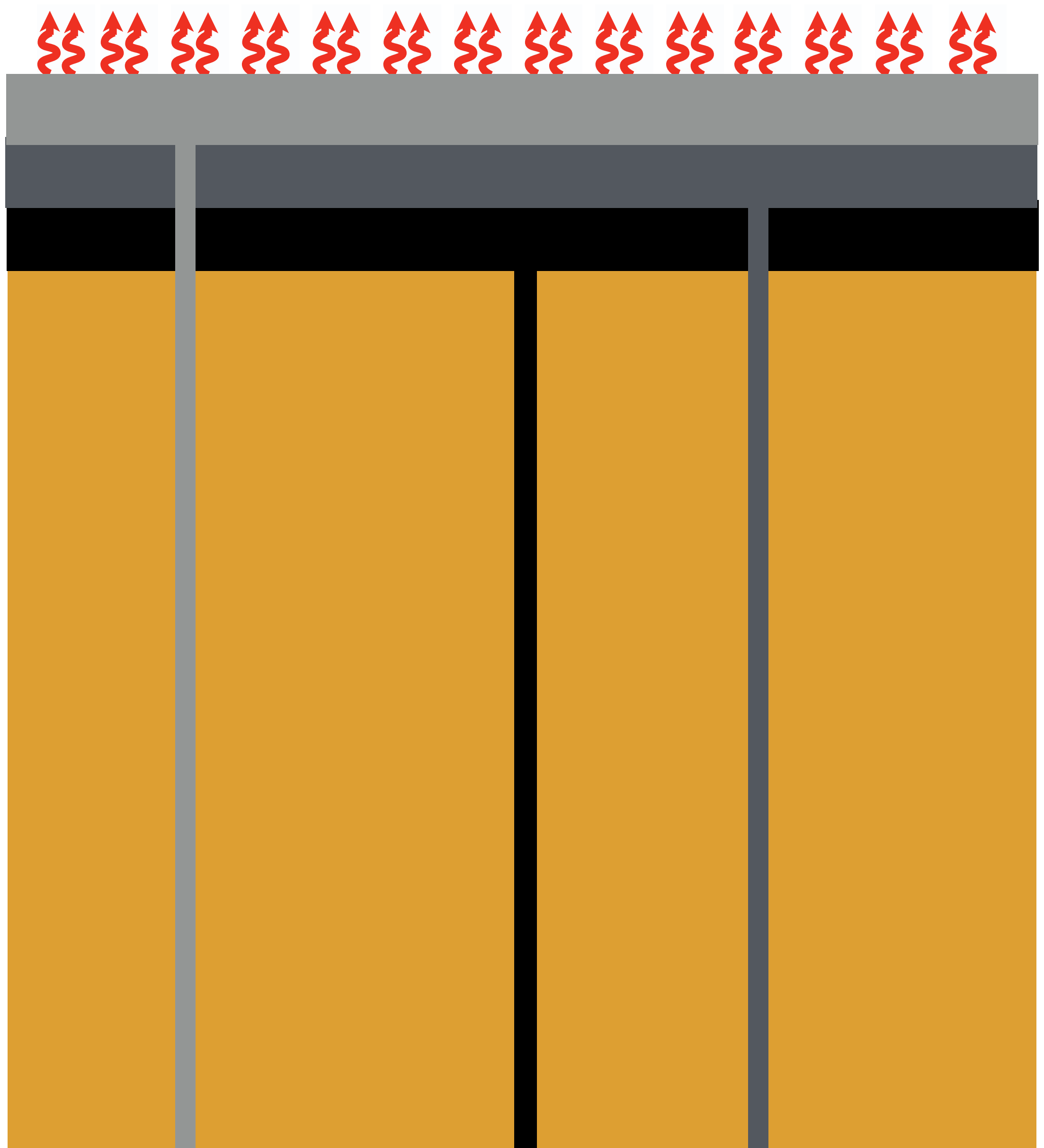

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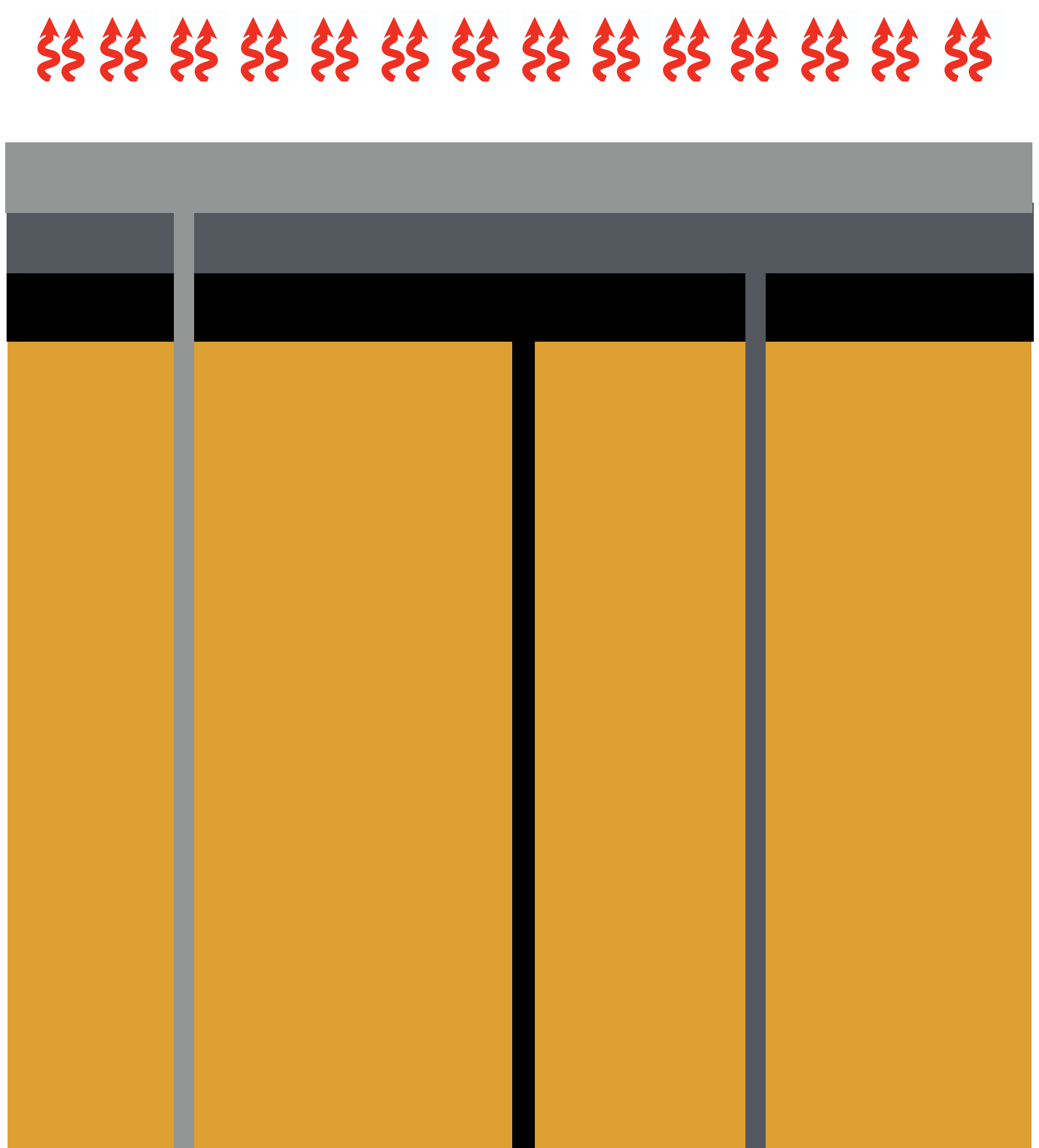

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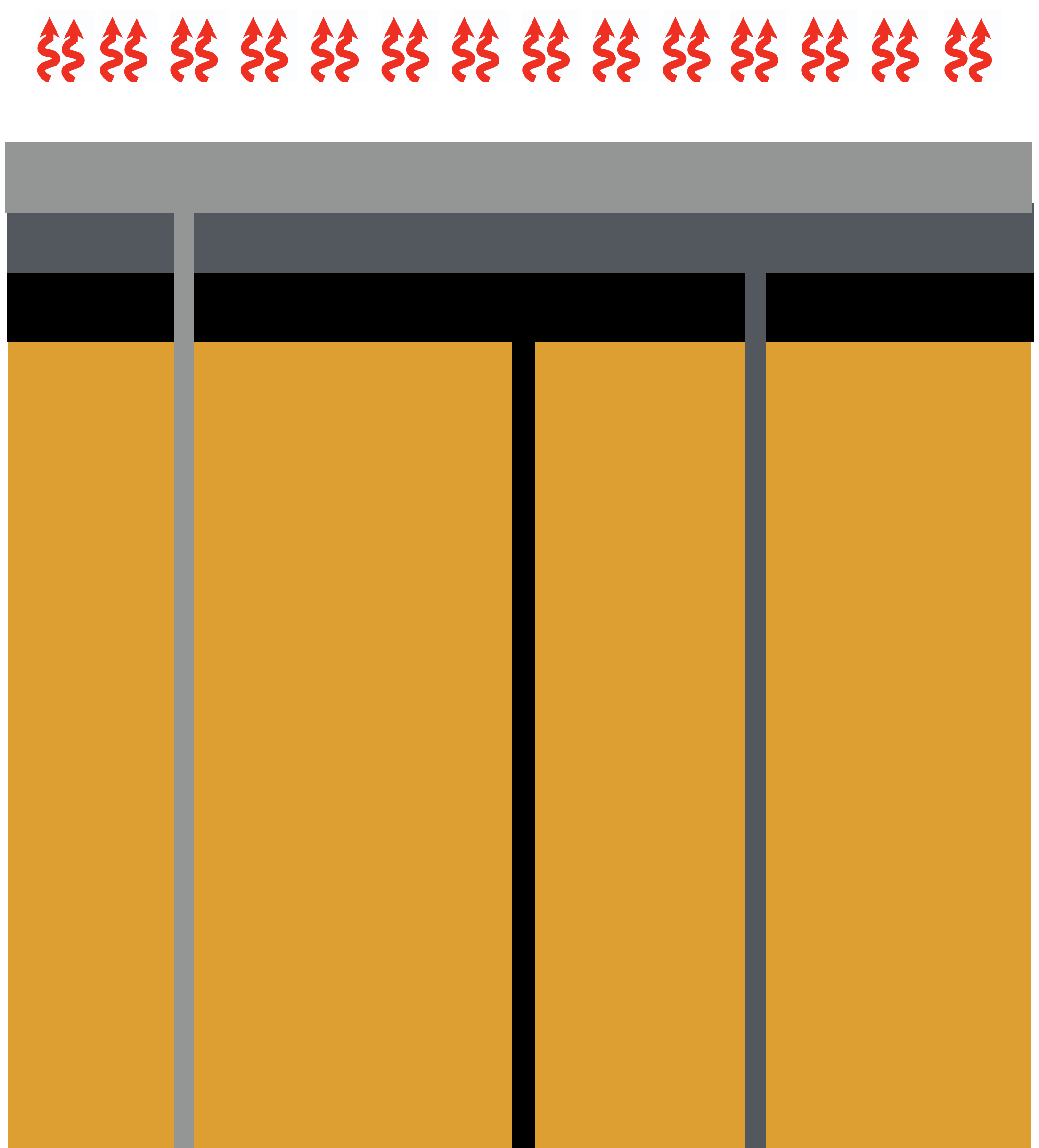
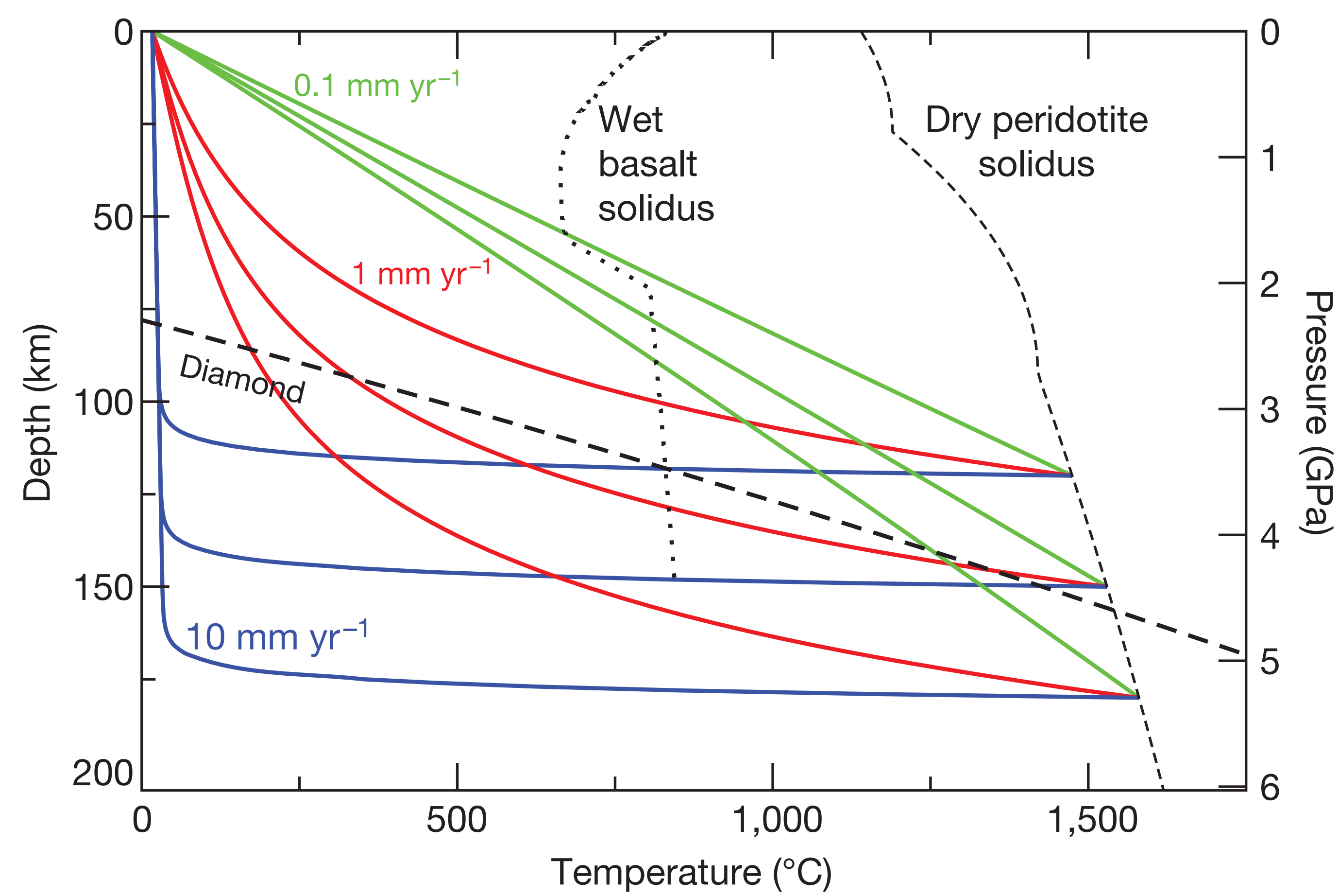
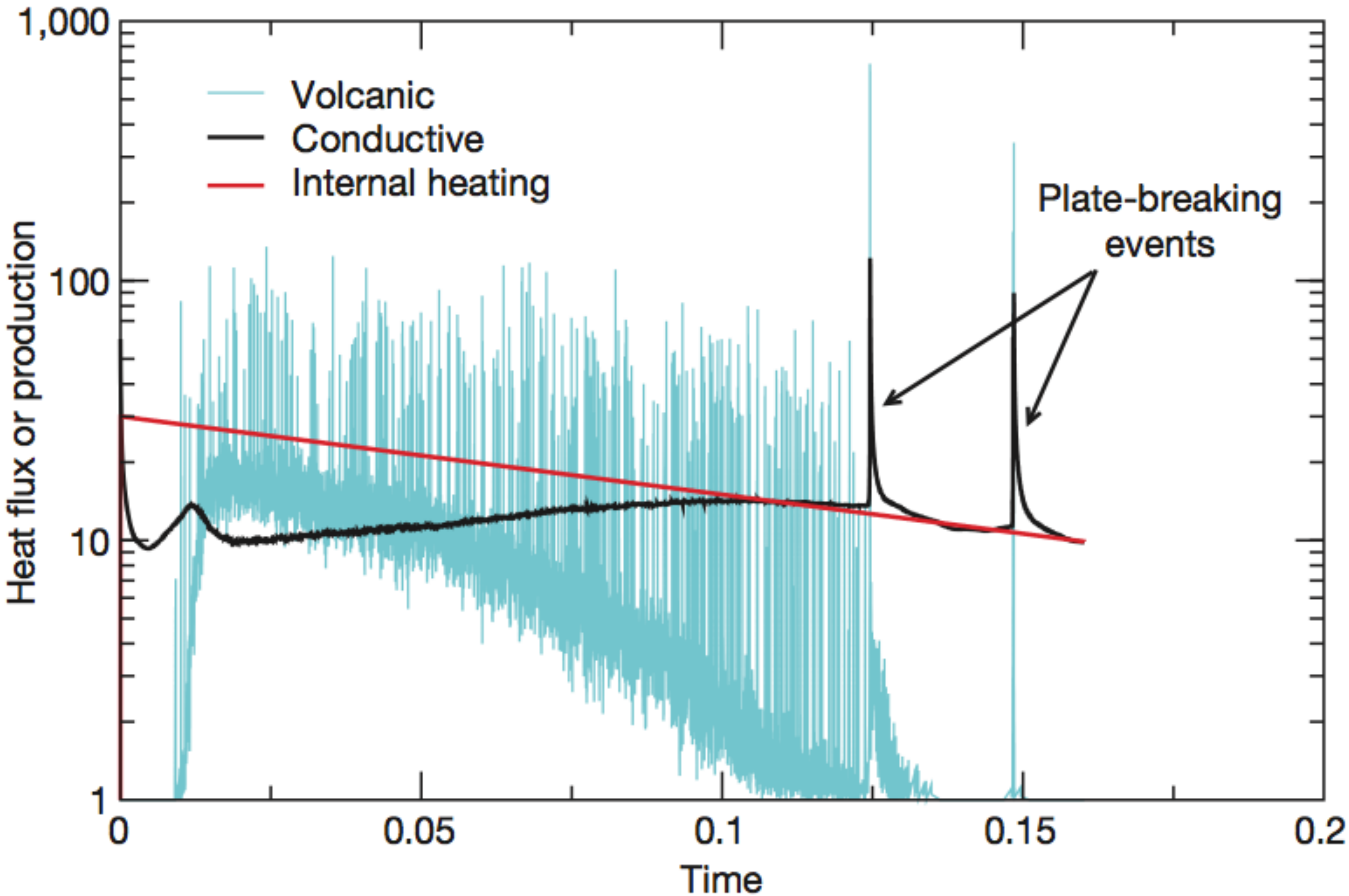
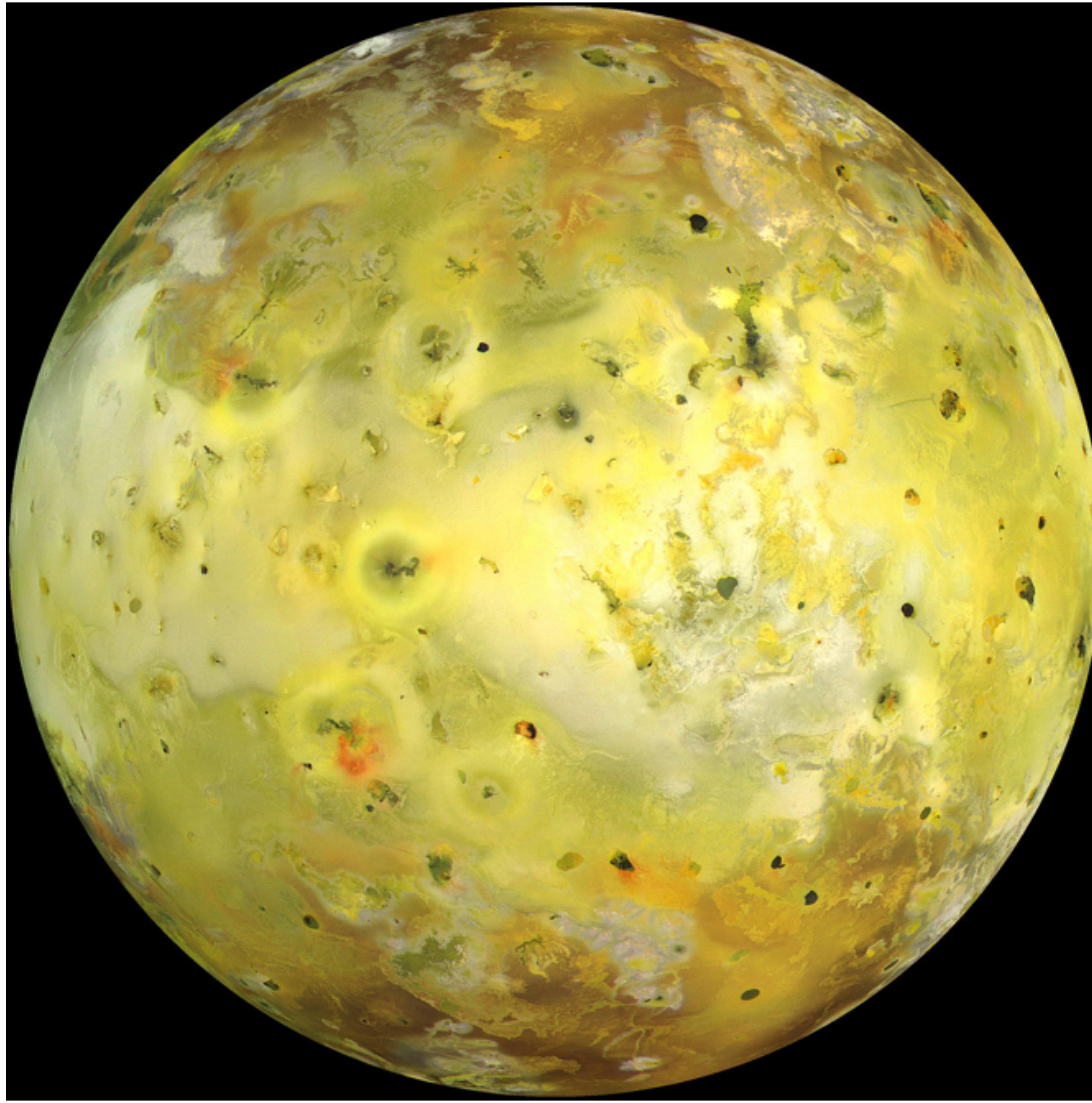




Transição: “Tubos de calor” para tectônica de placas



Io
satélite
de Júpiter



Fluxo térmico

"Tubos de calor"	Io
Tectônica de placas	Terra
"Tampa estagnada"	Marte Lua

Fluxo térmico

"Tubos de calor"	Io	
Tectônica de placas	Terra	
"Tampa estagnada"	Marte	
	Lua	$12\ \mathrm{mW/m^2}$

Fluxo térmico

"Tubos de calor"	Io	
Tectônica de placas	Terra	
"Tampa estagnada"	Marte	$< 20\ \mathrm{mW/m^2}$
	Lua	$12\ \mathrm{mW/m^2}$

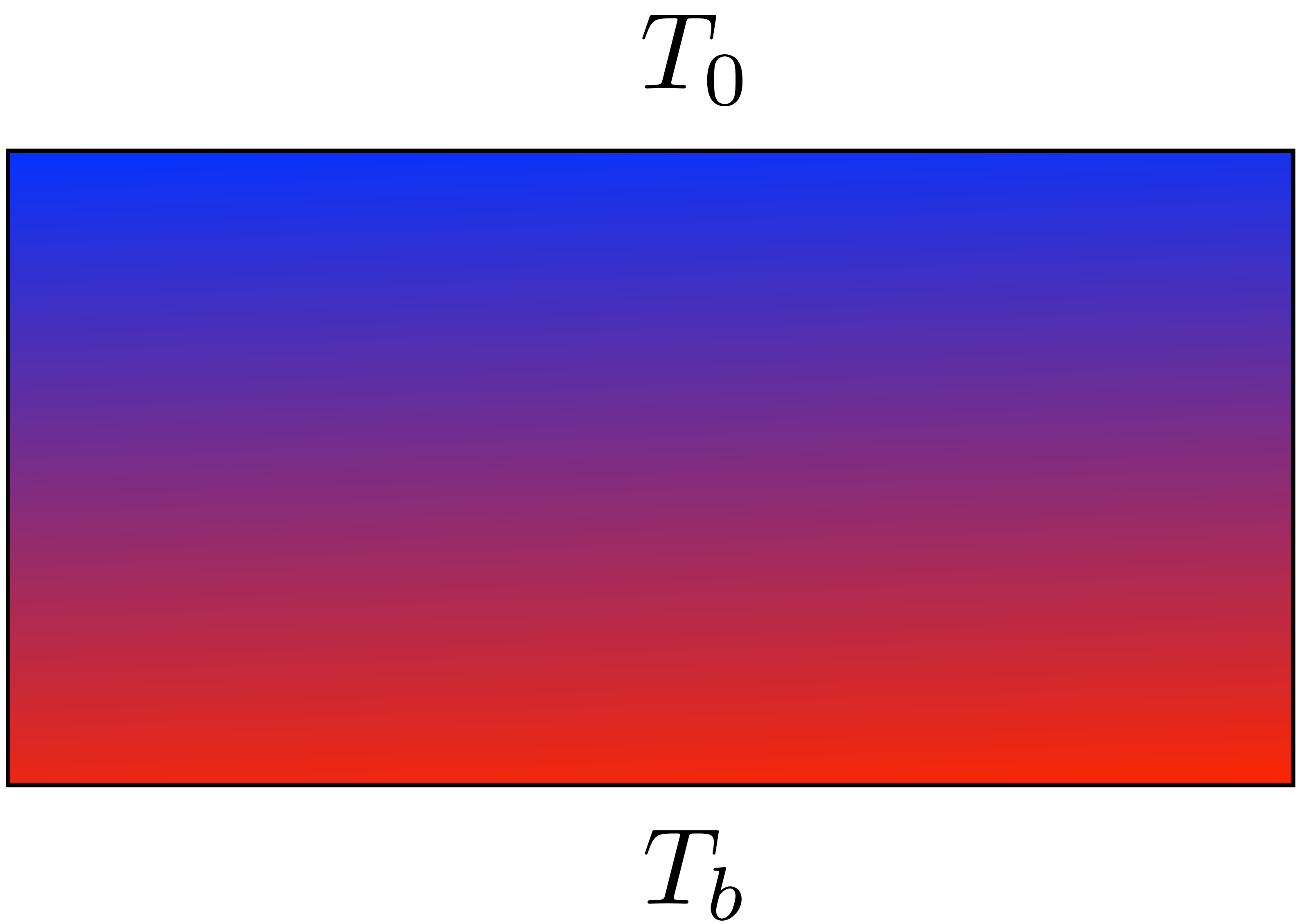
Fluxo térmico

"Tubos de calor"	Io	
Tectônica de placas	Terra	65 mW/m^2
"Tampa estagnada"	Marte	$< 20 \text{ mW/m}^2$
	Lua	12 mW/m^2

Fluxo térmico

"Tubos de calor"	Io	$2500\ \mathrm{mW/m^2}$
Tectônica de placas	Terra	$65\ \mathrm{mW/m^2}$
"Tampa estagnada"	Marte	$< 20\ \mathrm{mW/m^2}$
	Lua	$12\ \mathrm{mW/m^2}$

Condição de contorno: Temperatura superficial



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A climate induced transition in the tectonic style of a terrestrial planet

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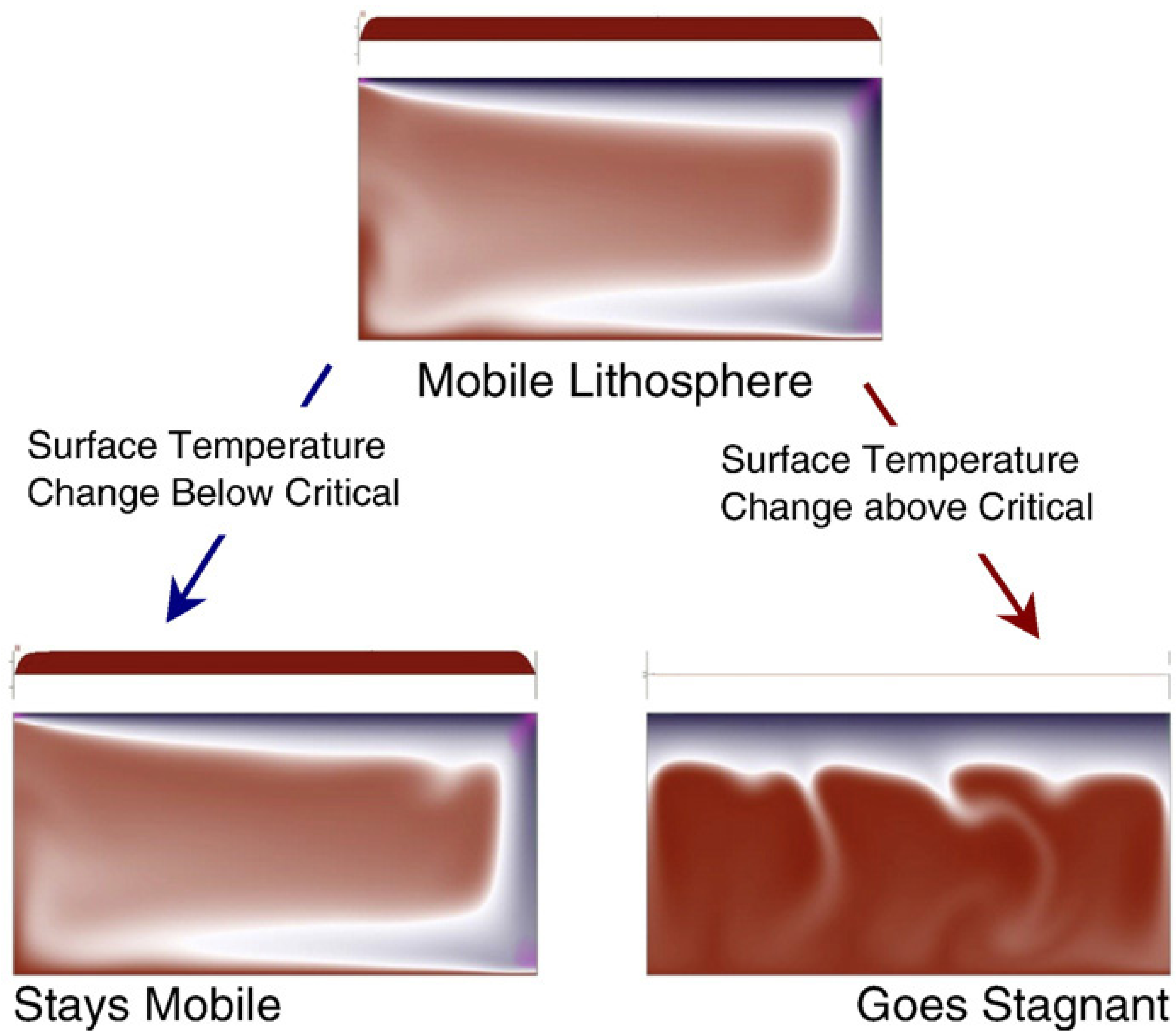
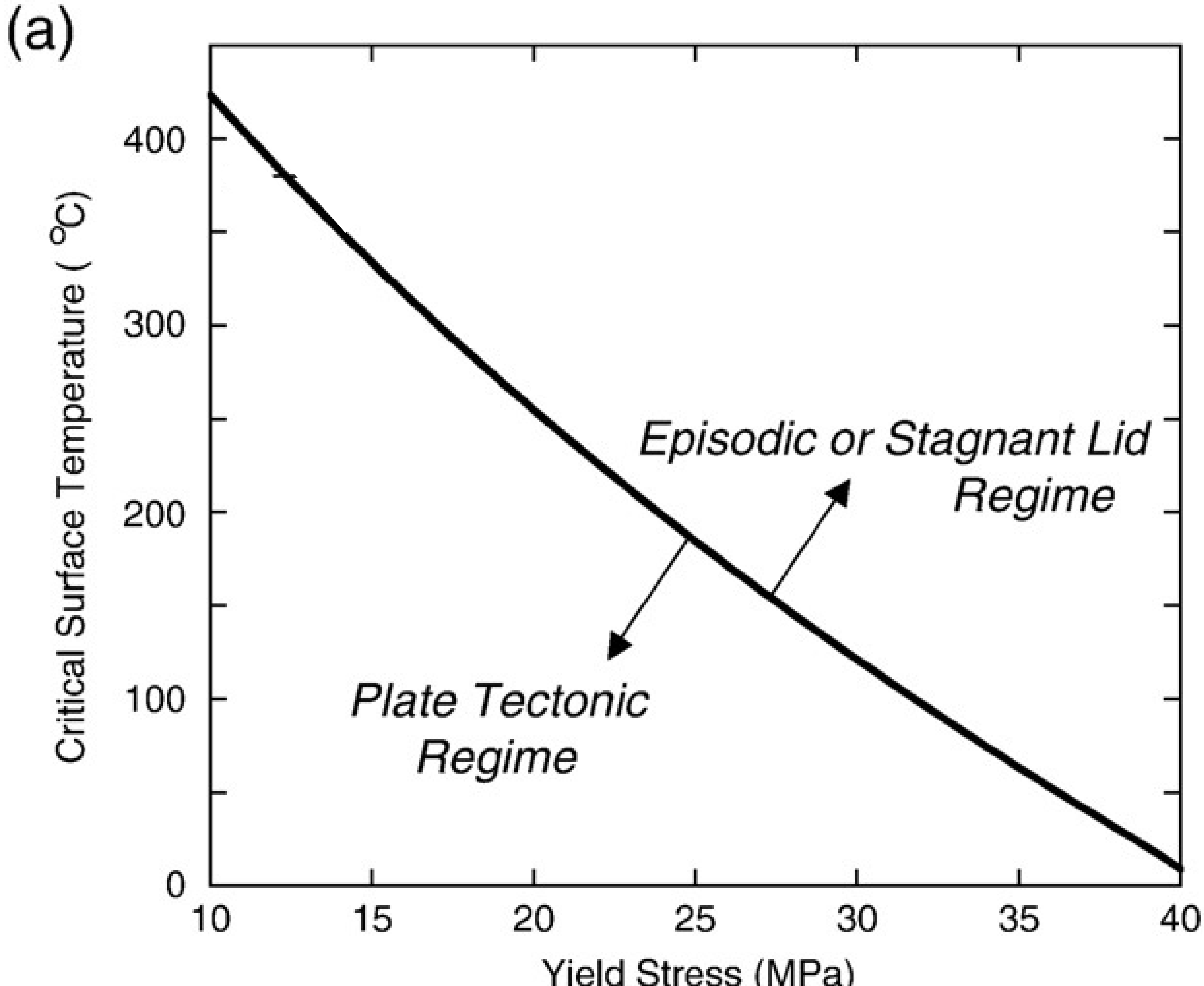
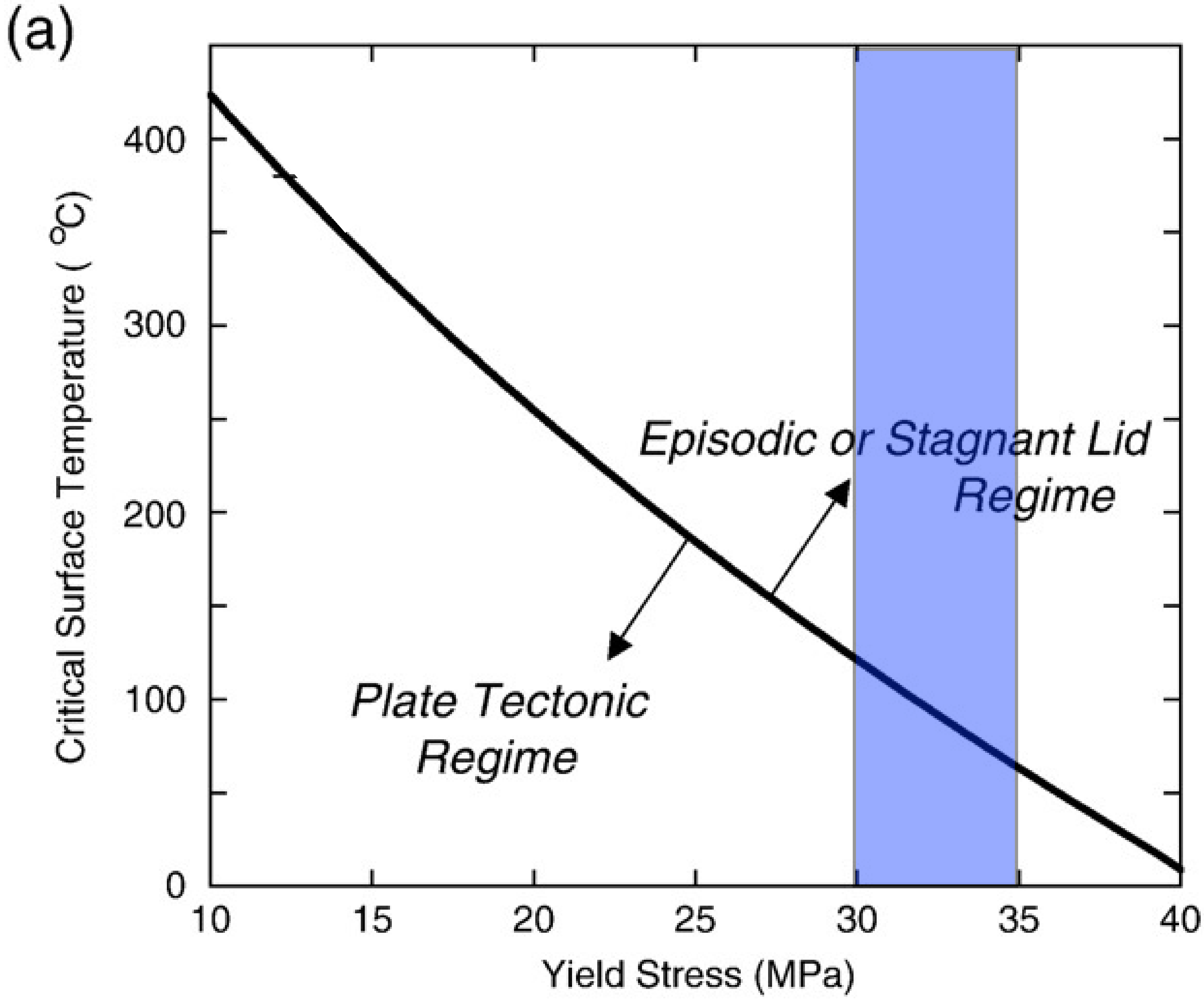
[b] Department of Earth and Ocean Sciences, The University of British Columbia, Vancouver, BC, V6T 1Z4, Canada M5S 1A7
[c] School of Mathematical Sciences, Building 28, Monash University, Victoria 3800, Australia





Lenardic *et al.* (2008) EPSL

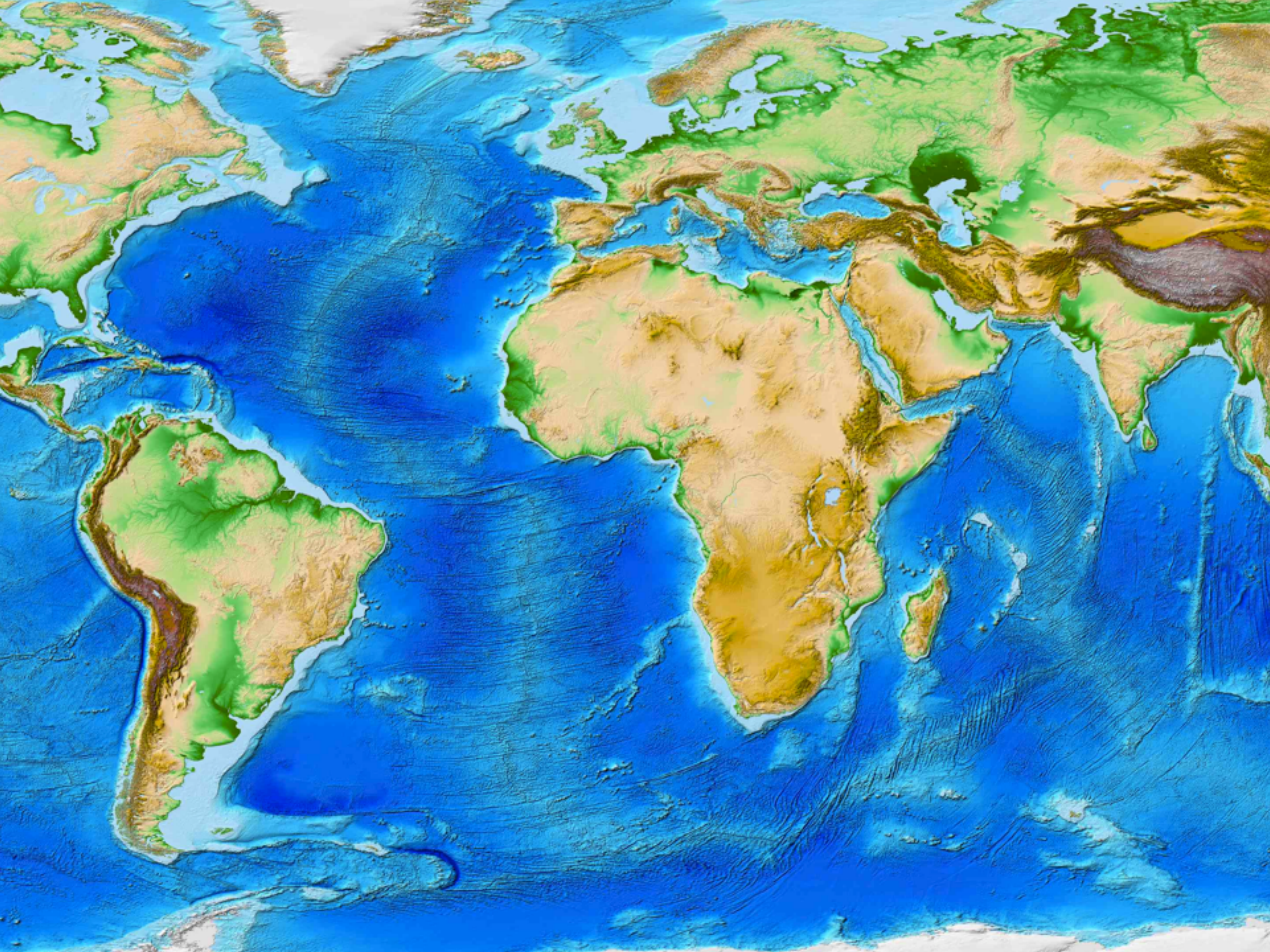


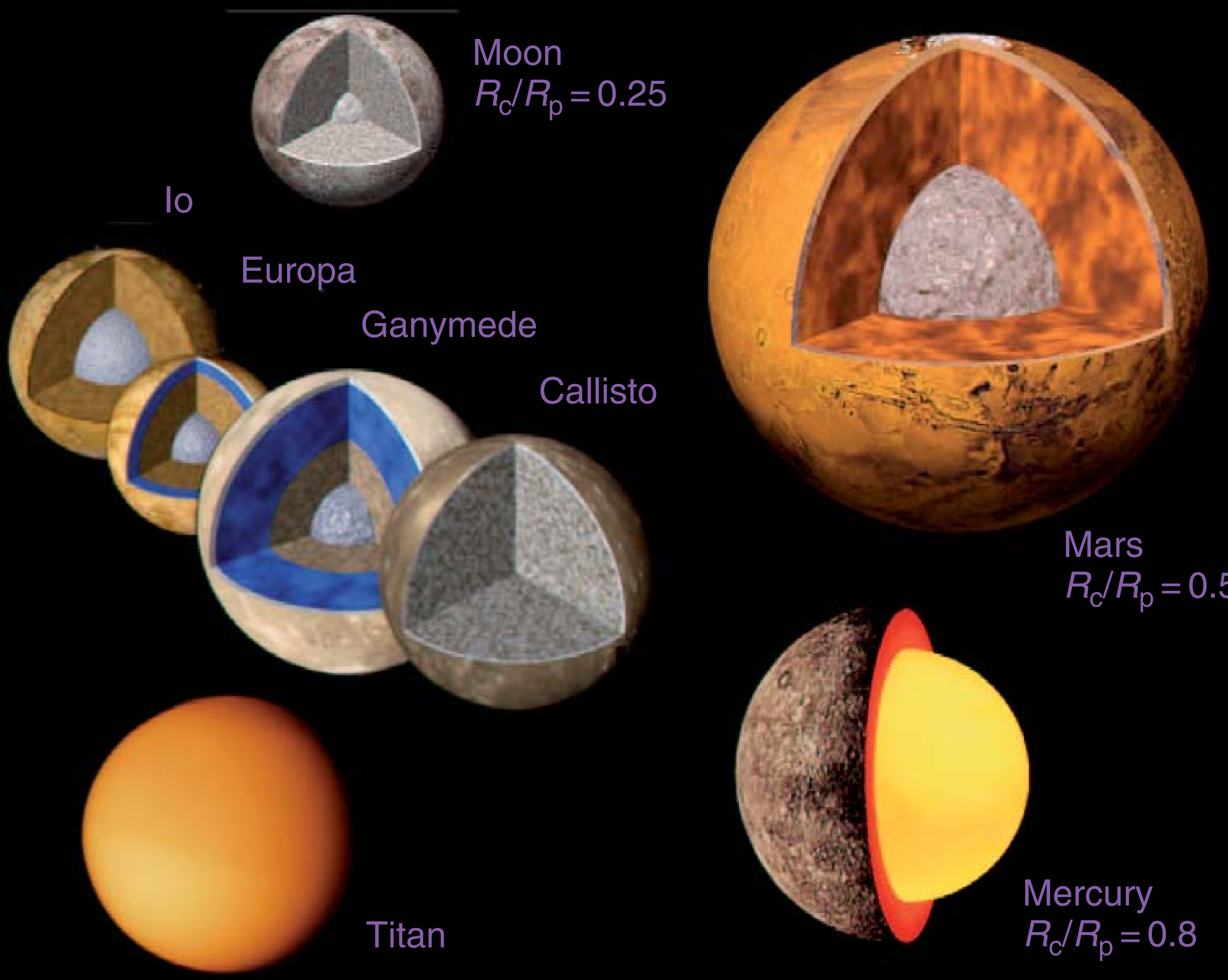
Lenardic *et al.* (2008) EPSL

Clima?

Tampa estagnada

Tectônica de placas





Moon
$R_c/R_p = 0.25$
Io
Europa
Ganymede
Callisto
Titan
Mars
$R_c/R_p = 0.5$
Mercury
$R_c/R_p = 0.8$